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SUMMARY OF RECENT SHORT-HAUL SYSTEMS STUDIES

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16. Abstract

This report summarizes and analyzes the results of several recent NASA-sponsored high density short-haul air transportation systems studies. Included are the total STOL systems analysis approach performed by the Douglas Aircraft Company and Lockheed Aircraft Corporation, a companion STOL composites study conducted by Douglas in conjunction with their STOL systems study, a STOL economic assessment study by the Aerospace Corporation, an evaluation of STOL aircraft with and without externally blown flaps by the Wichita Division of The Boeing Company, an alternative STOL systems study for the San Francisco Bay Area performed by Stanford University, and the quiet, clean experimental engine studies (QCSEE) performed in parallel by the General Electric Company and the Allison Division of the General Motors Corporation. The assumptions and results of these studies are summarized, their differences are analyzed, and the results are compared with those of in-house analyses performed by the Systems Studies Division of the NASA-Ames Research Center. Pertinent conclusions are developed and the more significant technology needs for the evaluation of viable short-haul transportation systems are identified.

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SUMMARY

This report summarizes and analyzes the results of several recent NASA-sponsored high density short-haul air transportation systems studies. These studies were conducted to evaluate the environmental and economic viability of STOL transport aircraft and to identify the associated technology requirements.

The scope of the systems studies varied considerably. Included are the total STOL systems analysis approach performed by the Douglas Aircraft Company and Lockheed Aircraft Corporation, a companion STOL composites study conducted by Douglas in conjunction with their STOL systems study, a STOL economic assessment study by The Aerospace Corporation, an evaluation of STOL aircraft with and without externally blown flaps by the Wichita Division of The Boeing Company, an alternative STOL systems study for the San Francisco Bay Area performed by Stanford Universtiy, and the quiet clean experimental engine studies (QCSEE) performed in parallel by the General Electric Company and the Allison Division of the General Motors Corporation. The assumptions and results of these studies are summarized, their differences are analyzed, and the results are compared with those of in-house analyses performed by the Systems Studies Division of the NASA-Ames Research Center. Pertinent conclusions are developed and the more significant technology needs for the evaluation of viable short-haul transportation systems are identified.

INTRODUCTION

Significant problems facing the national air transportation system have been recognized and analyzed in many government-sponsored studies in recent years. These include the Department of Transportation's ad hoc Air Traffic Control Advisory Committee Study, the Joint NASA/DOT CARD Policy Study, the Aviation Advisory Commission Study, and the Federal Aviation Administration's National Aviation System Policy and Planning Studies, to mention a few. There appears to be general agreement that congestion of the major airports and noise pollution are the most important factors inhibiting the growth and prosperity of the national air transportation industry.

In addition to economic viability, the key to the application of short takeoff and landing (STOL) systems to short-haul transportation is the potential capability of such systems to alleviate the critical problems of noise and congestion. As a result, several technical and economic studies of short-haul air transportation systems were conducted recently by NASA (refs. 1-8) to evaluate the environmental and economic viability of STOL transport aircraft and to identify the critical technology needs for further evolution of high-density short-haul air transportation systems.

Because of the variety of contractors involved in these studies and the differences in study guidelines, assumptions, and modeling techniques, the results often appear to be inconsistent. The purpose of this report is to identify and explain these differences, compare the results with NASA generated results, and analyze them within a consistent framework of assumptions and ground rules as a means of extracting the pertinent results. In Part I, the studies are described in terms of their objectives and scopes. The unmodified conclusions of each contractor are also presented. In Part II, an attempt is made to analyze the contractors' results on a consistent basis and in conjunction with results of NASA's analyses. Finally, on the basis of these evaluations, some major conclusions relative to STOL systems are derived by the authors.

In this report, as in the subject contracted studies, the word "STOL" refers to both propulsive lift and mechanical flap aircraft capable of takeoffs and landings on runway lengths ranging from 610 to 1219 m (2000 to 4000 ft). It should not be inferred that "STOL" and "short-haul" are necessarily synonymous simply because this report is concerned with short-haul air transportation systems. Furthermore, it should be noted that although the studies were concerned primarily with 1985 technology, the conclusions presented in this report represent a 1973 assessment of STOL systems.

Contributions by Jeffrey V. Bowles in support of the aircraft performance and noise analyses and the contribution by Cynthia L. Smith in support of the economics analysis are hereby acknowledged.

PART I. DESCRIPTION OF CONTRACTED SHORT-HAUL STUDIES

In an attempt to identify the technology advances offering the greatest potential benefits to the national air transportation system, numerous NASA-sponsored short-haul systems studies have recently been completed. This section describes the pertinent studies, summarizes their objectives, and presents the conclusions as taken from each contractor's report. The studies considered are:

1. Parallel STOL systems studies performed by the Douglas Aircraft Company and Lockheed Aircraft Corporation (refs. 1,2)

2. A composite materials study conducted by Douglas in conjunction with their STOL systems study (ref. 3)

3. The Aerospace Corporation's STOL economic assessment study (ref. 4)

4. The Boeing Company's evaluation of STOL aircraft with and without externally blown flaps (ref. 5)

5. A California corridor study performed by Stanford University (ref. 6) with primary emphasis on the San Francisco Bay Area

6. Quiet clean experimental engine studies (QCSEE) performed by General Electric and Allison Division of General Motors (refs. 7,8)

Except for the Boeing study, the technology readiness date was selected on the basis of a need for a new generation short-haul aircraft in the early or mid-1980s. The Boeing study was concerned with a mid-1970 technology readiness date. The QCSEE engine studies are included because they were phased to interact with the STOL system studies and provided all the engine data inputs to the latter.

STOL Systems Studies

In May 1972, the Douglas Aircraft Company and Lockheed-California and -Georgia Companies initiated parallel twelve-month studies Quiet Turbofan STOL Aircraft for Short-Haul Transportation under NASA Contracts NAS2-6994 and NAS2-6995, respectively. To obtain the broadest possible perspective in these studies, subcontracts were negotiated with several airlines. Air California, Allegheny, American, and United Airlines assisted Douglas in conducting its study; Allegheny and Eastern Airlines participated with and provided consulting service to Lockheed.

The objectives of these studies were:

To determine the relationships between quiet turbofan STOL aircraft characteristics and the economic and social viability of short-haul air transportation.

To identify critical technology problems requiring solution prior to introduction of STOL short-haul systems.

To define representative aircraft configurations, their characteristics and the costs associated with their development and operation.

To identify desirable technology advancements for improving STOL short-haul systems.

These studies were not intended to dictate specific lift concepts and transport aircraft, but rather were conceived to provide a realistic basis for analysis of the total short-haul air transportation system and to assess the associated technology requirements.

A matrix of aircraft using various high-lift systems and design parameters were considered as follows:

<u>Lift Systems</u>

- Externally blown flap (EBF)
- Upper surface blown jet flap (OTW)
- Augmentor wing (AW)
- Internally blown jet flap (IBF)
- Upper surface-internally blown jet flap hybrid (OTW/IBF)
- Mechanical flap (MF)

<u>Design Parameters</u>

- Passenger capacity: 50, 100, 150, 200
- Field length, m (ft); 457 (1500), 610 (2000), 914 (3000), 1219 (4000) (sea level, 35°C)

Range: 925 km (500 n.mi.)
Noise: 95 EPNdB at 152 m (500-ft) sideline

To be fully effective, the major components of a STOL transportation system must work in harmony. These components – aircraft, airports, and ATC – interact decisively on each other, and gains in one field may be nullified by obsolete procedures in another. All services, therefore, were designed to a high level performance. Variations in aircraft characteristics, airport geometry and location, and airline operations were analyzed to determine their effects on the market, operating economics, and community acceptance. In these studies, the total systems approach was considered to be critically important in analyzing the potential of STOL aircraft to reduce noise pollution and alleviate the increasing air corridor and terminal area congestion.

Despite some philosophical differences in the two contractors' results relative to preferred lift concepts, the significant conclusions are consistent. These include required and available field lengths, economic viability of STOL, the capability of STOL to reduce airside congestion and noise pollution, and the technology needs for STOL implementation.

The Douglas study conclusions are:

- STOL AIRCRAFT CHARACTERISTICS
  - STOL transportation systems appear to be economically viable.
  - Despite higher direct operating costs relative to CTOL, 150 passenger, 3000 foot STOL designs showed potential returns on investment of 20 percent.
  - Returns on investment for STOL 2000 foot designs varied from 8.5 to 12.5 percent. The need for this short field length is questionable, since the airport analysis indicated that a 3000 foot capability was available at almost every site examined.
  - A payload of approximately 150 passengers is the preferred size for the midpoint of the 1980-1990 period. This size is a proper balance between the economic advantage of larger payloads and the marketing benefits of schedule frequency.
  - For the short haul stage lengths studied, the block times were essentially insensitive to cruise speed.
  - Development of a new high-bypass-ratio, quiet, clean variable pitch fan engine in the 20,000 pound thrust class is required.
  - Mechanical flap aircraft improve with field length and are competitive with propulsive lift aircraft for 3000 foot field length.
  - Propulsive lift 2000 foot and mechanical flap 3000 foot aircraft require ride quality improvements.

- MARKETS
  - The United States civil market for a 150 passenger STOL short-haul aircraft is estimated to be:
    - 420 aircraft by 1985 for the representative national system which includes high-, medium- and lower-density city pairs.
    - 240 aircraft by 1985 and 320 aircraft by 1990 based on the higher-density city pairs alone.
  - The foreign civil market for the same aircraft, based on the higher-density city pairs alone, is estimated to be 320 aircraft by 1985 and 545 aircraft by 1990.
- NOISE
  - The cost of noise reduction runs high – particularly to reach the noise level established in this study as a goal (95 PNdB at 500 feet sideline distance).
  - All STOL designs provided significant noise reduction over current CTOL aircraft.
- IMPLEMENTATION
  - There are numerous existing airports which are favorably located to implement a STOL transportation system.
  - The earliest date for implementation of propulsive lift aircraft in an operating system is the 1982-83 period.

The Lockheed study conclusions are:

1. Expected growth in air travel will cause airport congestion in the 1980-1990 time frame which will be especially critical in the major East Coast hubs, Chicago, and Atlanta.

2. Recent actions in the public sector are threatening further expansion of the air transportation system. Aircraft movements and development of new airports have been and will continue to be subject to restrictions.

3. Quiet STOL aircraft, with 3000 to 4000 ft (914 to 1219 m) field lengths, can greatly reduce the current noise annoyance area around major airports. The quiet STOL designed to FAR 36-10 EPNdB has an 80 EPNdB contour area, which is only seven percent of the same contour area for current high fan pressure ratio jets. Further design reductions to FAR 36-19 EPNdB reduce the 80 EPNdB contour area to two percent of the noisy jet.

4. Quiet STOL aircraft, with 3000 to 4000 ft (914 to 1219 m) field lengths, are technically feasible in the 80's.

5. Favorable public reaction to quiet STOL aircraft is predicted. Carefully planned introduction of quiet aircraft can help foster a positive attitude toward air travel growth.

6. Utilization of STOL to provide airport congestion relief in the major Eastern hubs, Chicago, and Atlanta, will generate a market for over 300 STOL aircraft.

   a. Short-haul systems will probably be implemented initially to help relieve congestion at large hubs.

   b. As economic feasibility and community acceptance of short-haul is proven, it is expected that the system will expand to secondary airports. The induced market response can be expected to further stimulate the system growth.

   c. Major hubs can be relieved of runway congestion until about 1990.

   d. Congestion relief provided by STOL will also benefit CTOL by reducing future delays.

7. Individual airports, which are expected to experience congestion, can increase total capacity and relieve the forecasted congestion by adding STOL strips within existing boundaries.

   a. For the airports where STOL strips are added in this study, runway lengths of at least 3000 ft (914 m) are obtainable.

   b. "Canted" runways or a small amount of land acquisition or conversion may allow runways as long as 4000 ft (1219 m); detailed studies of each critical airport and in-depth discussions with their planners would be required before establishing a 4000 ft (1219 m) field length as a design criterion.

8. The three prime congested areas – NYC, Chicago, and Washington – can eliminate runway congestion of the metropolitan hub by a planned conversion of one existing commercial airport to an "all-STOL" reliever airport in each metropolitan area.

   a. The CTOL runways are retained for mixed operations during a gradual transition from CTOL to STOL, and for STOL emergency or overload operations after conversion to an all-STOL airport.

9. Secondary airports in the metropolitan hubs are available which have 5000 ft (1520 m) runways, but a low noise level is necessary to facilitate the acceptance of commercial service.

10. The preferred short-haul configuration depends on the maximum available field length at critical airports.

    a. If only 3000 ft (914 m) is available, propulsive lift aircraft configurations are required. Further analytical and experimental data are needed to refine choice of lift system although the OTW/IBF appears most promising.

    b. If 4000 ft (1219 m) is available, a mechanical flap configuration is preferable due to better economics.

11. Designing for reduced noise and reduced field length are compatible objectives.

12. Point design data are as follows for two outstanding candidates:

	Mechanical Flap	OTW/IBF
No. of passengers	148	148
Field Length, ft (m)	4000 (1219)	3000 (914)
Gross Weight, lbs (kg)	136,900 (62,000)	147,300 (66,900)
No. of Engines	2	2
Engine Thrust, SLS lbs (kg)	34,000 (15,400)	36,800 (16,600)
Unit Cost, dollars	8.71×10^6	9.35×10^6
DOC @ 250 n.mi., cents/assm	2.12	2.29
80 EPNdB Footprint Area, sq. mi. (sq. km)	3.1 (8.0)	4.5 (11.6)

13. The evolution and operation of a short-haul system using the Quiet STOL aircraft should consider the following factors:

    a. 148 passenger aircraft provide capacity for high density markets and maintain adequate frequency of schedules as well as allow operations on future less dense markets.

    b. Utilization of short-haul STOL airplanes should be initiated on potentially congested hub airports.

    c. Goals of 12 sq. mi (41 km^2) (80 EPNdB contour area) per landing and departure should be a goal for STOL introduction reducing to 4 sq miles (14 km^2) by the late 1980's.

    d. High STOL DOC's can be partially offset by a short-haul system that achieves low IOC's through a spartan operation.

    e. Short-haul STOL fares should be competitive with CTOL fares to attract required demand at the major airports.

    f. Development of semi-segregated short-haul system should be an evolutionary process.

    g. Effects of adding all-coach STOL aircraft to airline fleet operations are as follows:

        - Adding all-coach STOL with 2000 ft (610 m) field length capability, to first class/coach CTOL fleet or to all-coach CTOL fleet, lowers ROI.

        - Adding all-coach STOL, with 3000 to 4000 ft (914 to 1219 m) capability to first class/coach CTOL fleet, raises ROI.

        - Adding all-coach STOL, with 3000 to 4000 ft (914 to 1219 m) field length capability, to all-coach CTOL fleet, lowers ROI.

h. Secondary airport utilization should be initiated only after service at the major airports is established and the induced demand is apparent.

14. Phasing in of lower noise level requirements in the 1980's may well be accomplished in a manner analogous to the current fleet noise level approach which has been announced as an advanced notice of proposed rule making. If this occurs the airline operator will find it advantageous to introduce quiet STOL aircraft to his fleet to lower the average fleet noise so he can realize a longer useful life from his inventory of noisier aircraft.

Composite Materials Study

As part of the systems studies just described, the contractors were to identify advanced technologies with high potential for economic and/or performance improvements. One of the most potentially important of these technologies is the use of advanced composite material in the primary airframe structure. The composite materials study, performed by Douglas Aircraft Company (ref. 3), determined the potential costs and benefits associated with the application of composite materials to civil STOL aircraft in sufficient detail to establish the net economic advantage of such materials. To accomplish this objective it was necessary to determine all the costs associated with producing large quantities of composite material flight hardware as well as those associated with operating and maintaining a fleet of aircraft with composite material structure.

The Douglas approach included the following tasks: (1) Development of a general method of cost benefit analysis for the application of advanced filamentary composites to civil aircraft; (2) generating composite material structure cost and weight data with emphasis on production costs; (3) performing a benefit analysis using the methodology developed in task 1 and the data generated in task 2 to establish structural components and concepts for which maximum benefits are achievable and to arrive at the overall benefit due to composites; and (4) undertaking a sensitivity analysis to assess the effect of assumptions on the results and to define those items that affect the results most significantly.

Because of the relatively high sensitivity of aircraft economics to production costs and because of the present uncertainty of these costs for composites, emphasis was on establishing reliable, detailed production costs. As a consequence, maintenance costs were not studied in depth, and information from past studies was used.

The conclusions of this study are as follows:

- Primary advanced composite material used was graphite/epoxy, with smaller amounts of fiberglass/epoxy, PRD-49/epoxy, and boron/epoxy also used. Ranges of material costs were assumed, and for graphite/epoxy varied from a low of $10/lb ($22/kg) to a high of $30/lb ($66/kg) with a nominal value of $25/lb ($55/kg).

- Total saving in takeoff gross weight (TOGW) was 16,700 pounds (7580 kg), or 11 percent. The saving in manufacturer's empty weight (MEW) was 15,500 pounds (7000 kg), or 16 percent.

- For the four main airframe components considered, the total weight saving was 10,700 pounds (4900 kg), or 23 percent.

- Total amount of composite material used for the four components listed above was 14,200 pounds (6500 kg), or 40 percent of the resized composite airframe. Of the total composite material used, 79 percent was graphite/epoxy. Principal application was to the primary structure portion of the components, for which the total composite application was 10,500 pounds (4800 kg).

- Total material costs were 26 percent of the nominal airframe cost for the composite aircraft, compared to 23 percent for the baseline aircraft. For the composite airframe, composite materials represented 47 percent of the total raw material costs (based on the nominal value).

- For the composite airframe, total manufacturing labor costs decreased by 160,000 dollars or 5 percent, and material costs increased by 260,000 dollars, or 17 percent. Tooling was found to decrease by 152,000 dollars, or 21 percent, and quality assurance increased by 88,000 dollars, or 22 percent.

- Based on the nominal material cost, total airframe production costs increased by only 0.7 percent while the total aircraft price decreased by 31,000 dollars, or 0.3 percent, because of decreased cost for the lower thrust engines required for the composite airplane.

- Based on the nominal graphite/epoxy material price and results of the UAL study, total maintenance costs increased by 10.1 percent.

- A range of direct operating cost (DOC) was developed and varied from a decrease of 3.4 percent to an increase of 3.5 percent, depending on material and maintenance costs.

- A corresponding range of return on investment (ROI) was developed, and varied from an increase of 7.4 percent to a decrease of 4.3 percent, corresponding to the above values of DOC.

- For the alternate structural configuration (reinforced metal fuselage), TOGW was developed as 136,000 pounds (61,700 kg). DOC was 1.5 percent lower than the baseline aircraft, while the ROI was 3.1 percent higher, based on nominal material prices and UAL maintenance factors for the composite components.

- A systems operation analysis showed that there were no significant operational advantages due to the decreased size and weight of the composite aircraft, nor was there any significant impact on STOL viability. Noise footprint area, however, decreased by 8 percent, and could be significant depending on operational conditions.

- Comparison of results with other applicable studies indicates general agreement on amount of weight savings discussed above. There is also general agreement on price, in that total price of a composite aircraft is expected to be approximately the same as a conventional metal aircraft.

- Composite airframe fabrication and assembly labor costs were found to be the most significant production costs that can be influenced by composite materials, amounting to 42 percent of total production costs for the composite aircraft.

- Maintenance costs for the composite aircraft were found to be the least well-known and one of the most signifcant operating cost items influenced by composites for the aircraft studied.

- Comparison of short-range and long-range aircraft showed that the value of weight savings tended to be higher for the long-range aircraft, and that value of initial aircraft cost savings tended to be higher for the short-range aircraft. Both results are based on preliminary study and are sensitive to basic assumptions.

- Application of composites for greatest cost effectiveness varies and is primarily dependent on material, manufacturing, and maintenance costs. For wings, greater cost effectiveness was found to be in the wing skins, with somewhat less effectivity obtained in the wing substructure. With UAL composite maintenance factors, the reinforced metal fuselage concept was more cost-effective than the all-composite fuselage; with metal aircraft maintenance factors, the all-composite fuselage design developed the same DOC as the reinforced metal design.

STOL Economic Assessment Study

The Aerospace Corporation has been under contract for several years to the Ames Research Center for the purpose of studying short-haul air transportation systems. These studies concentrated on the California Corridor and the Midwest Triangle. In May 1972, the contract was extended to update these studies with respect to noise impact on the community. At the same time, the Aerospace Corporation began a separate task under contract to the Systems Studies Division to use the previously developed methodology to study STOL systems in the Northeast Corridor.

Results from these studies were combined into a single volume to allow regional comparisons (ref. 4). The objectives of the combined study were:

To examine the impact of technological, economic, and operational characteristics of STOL transportation systems in selected arenas.

To determine the economic viability of STOL airline systems required to absorb the full cost of achieving compatibility with environmental noise constraints.

Aerospace based the study on a STOL aircraft concept furnished by the NASA. This was an augmentor wing, turbofan-powered aircraft having hot day field length capability of 610 m (2000 ft). The engine performance characteristics were based on the initial phase of the QCSEE engine technology program. The airframe weight statement was based on an early augmentor wing concept incorporating advanced composite structures. To maximize congestion relief at hub airports, and evaluate the quiet engine technology in its most severe environment, the study avoided the use of hub airports to the greatest extent possible, and concentrated on general aviation community airports located close to the centers of demand. New STOLports were to be constructed only where they were essential to support high-density routes where the full costs of their development and operation could be underwritten by the revenue potential of the STOL system. The latter was assumed to be implemented completely as a private venture. No government subsidy was assumed for the development of the facilities required to support STOL operations, except for FAA-furnished ATC facilities; nor was the STOL system required to support unprofitable low density service with revenues obtained from the more profitable routes.

An important difference between this study and the Douglas and Lockheed studies is that fare was not assumed to be the same as currently set by CAB. In the Aerospace study, fare is a variable output depending on the ROI desired. Making the system self-supporting generally tends to limit it to the high-density profitable routes, and therefore the scope of the transporting network could be expected to be smaller than that for the other studies. In addition, the Aerospace study of noise sensitivity was based on the use of the NEF 30 as a measure of acceptability. These differences in guidelines and constraints lead to some variations in the conclusions regarding field lengths, economic viability, and noise pollution. These are discussed in subsequent sections of this report.

The Aerospace study conclusions are:

A. STOL PATRONAGE POTENTIAL

When a STOL airline system, yielding a return on investment (ROI) of 8 percent and utilizing a 150-passenger aircraft, was placed in competition with a CTOL airline system, the combined systems produced a 6-percent increase in projected 1980 short haul origin and destination air travel within the California Corridor, a 66-percent increase in the Midwest Triangle, and an 88-percent increase in the Northeast Corridor. The STOL system attracted over 95 percent of the air travelers between the city pairs of the Northeast Corridor and the Midwest Triangle, but only about one-half of the air travelers in the California Corridor.

High-density STOL service between cities separated by distances of 100 miles or less appeared marginal due, primarily, to the highly competitive auto trip time and cost factors.

B. PRINCIPAL STOL SYSTEM ATTRIBUTES

The favorable potential of STOL service in both the Northeast Corridor and the Midwest Triangle can be attributed to a substantial reduction in both air travel time and cost. The block times of the STOL system are shorter than those of contemporary CTOL systems, which are assumed to continue operation in today's congested air and ground environments. Lower STOL fares reflect the shorter block times, and the resulting lower operating costs further enhance the short haul system's attractiveness. The fares also reflect, but to a lesser degree, the lower operating costs of a system whose service is virtually all high density, similar to current California intrastate operations.

The existing CTOL system in the California Corridor has superior time and cost characteristics and is less congested than those in the Northeast Corridor and the Midwest Triangle. An examination of the dominant city pair of this arena, Los Angeles-San Francisco, indicated that about one-half of the 1980 origin and destination travelers would use the STOL system in spite of lower CTOL fares. Primary factors leading to this projection were STOLports located close to the centers of demand and minimum port-processing times. The STOL system succeeds best where CTOL congestion is highest or where geography or land use precludes locating CTOL airports nearer the centers of travel demand.

C. AIRCRAFT SIZE

Examination of STOL aircraft in sizes ranging from 50 to 200 passengers indicated that, because of the advantages of low operating costs, the 200-passenger configuration generated a higher passenger demand within the three arenas than did the smaller sizes. However, the levels of patronage were very similar for capacities between 100 and 200 passengers. At an 8-percent ROI, demand dropped less than 10 percent between 200- and 100-passenger sizes. However, between the 100- and 50-passenger sizes, operating efficiencies deteriorated rapidly, resulting in higher fares and corresponding reductions in STOL patronage. The combined results from all three arenas indicated that 50-passenger aircraft attracted only 65 percent of the 200-passenger demand. Where the competition with STOL was severe, as is the case in the California Corridor, the effect is more pronounced, with the 50-passenger aircraft attracting only 20 percent of the patronage drawn when using a 200-passenger aircraft.

D. FLEET REQUIREMENTS

Fleet-size requirements reflect the demand sensitivity to aircraft size. Where demand is less sensitive to aircraft size, as in the Northeast Corridor and the Midwest Triangle, reducing aircraft capacity from 100 to 50 passenger <u>increases</u> the required number of aircraft by over 60 percent. Where demand is very sensitive to size, as in California, the same size variation <u>decreases</u> the aircraft requirement by 30 percent.

The number of 150-passenger aircraft required to support a system configured to yield an 8-percent ROI in each of the three arenas is as follows:

- California - 14
- Midwest - 6
- Northeast - 32

E. EXTENDED RANGE POTENTIAL

A limited passenger version of the 500 statute mile aircraft design, operating on four service paths between two Chicago and three New York STOLports, attracts over 90 percent of all origin and destination air travelers in this market while still retaining economic viability. The requirement for 24 additional 150-passenger aircraft to implement this service suggests that extended-range applications may be a very important element in building an adequate production-base potential.

F. NOISE IMPACT

The STOL aircraft defined for this study has almost no adverse noise impact relative to the land use surrounding the selected airports. In those few cases where dedicated STOLports are assumed, the NEF=30 contour generated by the operations of STOL aircraft is contained totally within the airport boundaries. Therefore, special departure and approach corridors are not required to alleviate noise impact.

G. AIR POLLUTION IMPACT

The preliminary estimate of the amount of carbon monoxide, hydrocarbons, and oxides of nitrogen produced by the STOL aircraft system shows the level of these pollutants to be considerably lower than that of corresponding emissions from current-technology CTOL aircraft. Segregated airport operations and dedicated airspace help ensure low pollution levels by holding engine-on ground time to a minimum.

H. HUB AIRPORT CONGESTION RELIEF

Both ground and air congestion at major airports currently providing short haul air service can be relieved by dispersing short haul operations. The maximum relief at the four hub airports studied occurred at La Guardia, where 15 percent of the traffic could be removed by instituting STOL service at neighborhood airports. This could delay the need for expanding La Guardia capacity by approximately three years.

I. OPEN ISSUES–AIRCRAFT DESIGN ALTERNATIVES

In retrospect, two issues were identified which, while beyond the scope of the current study, are nevertheless significant in the continuing evaluation of the technology needed to satisfy future short haul air transportation requirements:

- The first issue is a better understanding of the sensitivity of total system economics and environmental impact to aircraft noise level. This study has shown that 95 EPNdB at a sideline distance of 500 feet may represent a higher level of noise suppression than is initially required. Some relaxation of this requirement may improve system economics without jeopardizing community acceptance, resulting in greater STOL patronage and a correspondingly higher production base.

- The second issue involves a better understanding of preferred field length capability. STOL aircraft designed to a 2000-foot, hot day balanced field length tend to yield a steeper terminal area flight profile (relative to longer field length designs) which, for equal noise levels, would reduce the noise impact. In addition, shorter field length capability permits STOL systems to operate out of a larger number of existing airports and provides more flexibility for siting new STOLports. New STOLport site acquisition and construction costs would also be lower with shorter field lengths. Countering these attributes are the higher development and operating costs anticipated for the shorter field length aircraft designs.

To better identify the appropriate design goals and required supporting technology, both with respect to aircraft noise levels and field length capability, additional aircraft concepts should be evaluated on a basis comparable to that in the present study.

STOL EBF Evaluation Study

A related NASA-sponsored study was conducted for Langley Research Center by The Boeing Company at Wichita (ref. 5). The Boeing study considers the design of aircraft similar to those in the Lockheed and Douglas studies, and is included in this report for comparative purposes. The objectives of this study were:

To determine the effects of wing loading on the design of STOL transports using mechanical flap systems and externally blown flap (EBF) systems.

To compare the mechanical flap STOL aircraft with EBF STOL aircraft on a gross weight basis and on a preliminary economic basis.

An important factor in this study was the assumption that an active gust and load alleviation system was incorporated on all aircraft. One guideline that hinders direct comparisons with the other studies is the assumed 1975 level of technology in terms of propulsion, weights, supercritical wing aerodynamics, and acoustics. A specific noise criterion was not a constraint of this study. However, an equivalent level of noise attenuation was applied to both the mechanical flap and the EBF, except that a 10-dB noise increase was assigned to the EBF due to underwing blowing.

A matrix of 18 aircraft using mechanical flap and EBF systems was considered as follows:

	Design Parameters		
Passenger capacity	40	150	300
Field length, m (ft)	610 (2000)	762 (2500)	1066 (3500)
Range	3 unrefueled, 462 km (250 n.mi.) stage lengths, plus reserves		

Since this study was primarily limited to aircraft design and was not a systems analysis, the comparisons with other study results in this report will be limited to aircraft design only.

The conclusions of the Boeing-Wichita study are:

A conclusion of the feasibility study of Reference 1 (Boeing document: Low-Wing-Loading STOL Transport Ride Smoothing Feasibility Study. D3-8514-2, 1971) was that through the use of modern control systems technology to provide ride smoothing, a low-wing-loading mechanical flap STOL airplane appears competitive with a high-wing-loading powered lift design (airplane Model 751 of Reference 1). Because powered lift was not relied upon, the resulting configuration offered advantages in system simplicity, reliability, and safety. A more significant conclusion of the present study is that through the use of an active control system for gust load alleviation, as well as for ride smoothing, and for the powered-lift airworthiness standards assumed, low-wing-loading mechanical flap airplanes are competitive with externally blown flap airplanes over a wide range of payloads and field lengths. Therefore, advantages in system simplicity, reliability, and safety can be realized regardless of the size of the airplane or the STOL field length.

For the range of field lengths and payloads investigated the MF configurations were lighter, quieter, and more economical than the EBF configurations.

On the average, the EBF airplanes were about 12 percent heavier than the MF airplanes for the same mission and field length.

Gust load alleviation provides a large gross weight reduction for airplanes with field lengths shorter than 2,500 feet. Without gust load alleviation the MF airplanes were heavier than the EBF airplanes for field lengths less than about 2,400 ft.

The EBF configurations are very sensitive to landing approach safety margins and go-around procedures. The EBF configuration approach speed was constrained by a requirement to have a $\Delta\alpha$ safety margin of 15 degrees for vertical gust protection at the approach power setting. Installed T/W was designed by a requirement to maintain level flight after loss of the most critical engine with the approach flap setting. As an example of the sensitivity consider a reduction of the $\Delta\alpha = 15$ degree gust margin to 10 degrees which would offer less gust protection than today's CTOL airplanes; and allow a slight descent after engine failure. The EBF airplane could approach at a lower speed (have higher wing loading) and could possibly be designed with a lower installed T/W (depends on whether or not the required go-around climb gradient becomes critical). Preliminary analyses indicate that this combination would result in an 11 percent gross weight reduction.

The MF airplanes have a $1.3V_s$ approach speed which allows 16 degrees of margin for gust protection and they can meet the engine out climb gradients without a configuration change.

The EBF configurations require a more complex vertical and horizontal tails to keep the surfaces from being excessively large.

The EBF airplane maximum sideline noise is about 12 EPNdB higher than the MF airplane at 500 feet. The 95 EPNdB footprint acreage of the EBF airplane is 11 times as large as the MF airplane for takeoff and a factor of 7 larger for the summation of approach and takeoff.

The EBF airplane DOC is about 10 percent higher than the MF airplane in terms of cents per seat statute miles versus range in nautical miles. This percentage remains fairly constant for the DOC sensitivity to payload and the DOC sensitivity to field length. In addition to the above comparison cost analyses for both the MF configuration and the EBF configuration show that: trip distances less than 400 NM begin to get expensive; a 150 passenger payload and 2,500 feet F.A.R. field length are reasonable design goals.

California Corridor Study

In October 1972, the Department of Aeronautics and Astronautics at Stanford University, under the Stanford Transportation Research Program, began studies of short-haul air transportation in the California Corridor under NASA Contract NAS2-7199. The contract supported a large number of students brought together in a multidisciplinary research team. The objectives of these studies were:

To determine the effects of design runway length on the economics and traffic demand for 1985 short-haul air transportation system.

To study community acceptance at new commercial airports for short-haul service.

To conduct sensitivity studies of the effects of varying rate of return on investment (ROI) and fuel costs.

As a result of a fundamental guideline in the Stanford study, only the aircraft concepts developed in the McDonnell Douglas STOL systems study were used and comparisons were made for the 610- and 914-m (200- and 3000-ft) field length aircraft. A prime constraint on the study limited the systems under consideration to the California Corridor, and more specifically, the route from the San Francisco Bay Area to the Greater Los Angeles area. The 610-m (2000-ft) system utilized Central Business District (CBD) STOLports and it was assumed that the CBD STOLport could not accommodate a 914-m (3000-ft) runway. This assumption was the major impetus for studying the 610-m (2000-ft) case, since all other STOLports were placed on existing airports where the runway is greater than 610-m (2000-ft). A major question addressed is when do the access advantages of a

CBD STOLport outweigh the higher operating cost of a 610-m (2000-ft) runway aircraft. Despite the differences in scope between this study and those of the Douglas and Lockheed studies, conclusions regarding available and required field lengths were consistent. Differences in methodology of systems analysis, systems economics, and assumptions of fares are addressed in subsequent sections of this report.

The conclusions of the Stanford study are:

This study has clearly shown the substantial economic superiority – including all system costs – of a 3000-ft runway quiet short haul aircraft over a 2000-ft aircraft in the California corridor. The difference in fare is 23% with an ROI of 8% and 28% with an ROI of 12%. The 3000-ft aircraft attracts a 31% larger air travel market. There are no redeeming features to the 2000-ft system since the average system access cost savings with a CBD STOLport credited to the 2000-ft aircraft is small compared to the fare increments. Differences in noise and infrastructure costs are negligible compared to the fare differences. In addition the fuel consumption is 35% higher for the 2000-ft case.

Unique cases may exist elsewhere in the country where a 2000-ft airport can be built but a 3000-ft runway cannot. Such situations seem likely to be rare. Furthermore, the number of people who would benefit sufficiently from these special airport locations to justify the higher fare is small compared to the total market for high density short haul service. It does not seem efficient to penalize the many for the few. If a special aircraft type is built to serve a very few routes, the production quantity would be small. The cost will then be much increased and the fare disadvantage of the 2000-ft field length aircraft will be further accentuated.

The likelihood of developing a multi-terminal short haul air transportation system sited separately from existing metropolitan airports is small. Hostility can be expected wherever significant populations are close to the airport – making community acceptance highly unlikely. Nevertheless, general aviation airports located in growth-oriented communities on the urban periphery may have potential for development as individual additions to the existing system, improving service and relieving congestion at hub airports. It is probable that the runway lengths available, or capable of being made available, at these airports on the urban fringe are not particularly restrictive.

Our final conclusion takes the form of a question. If 3000-ft runway aircraft are so much more economical than 2000-ft aircraft, what is the optimum field length? The findings here suggest that 3500-ft, 4000-ft and possible longer field length aircraft should be studied to locate this optimum. It seems clear that the most economical aircraft will have a field length of at least 3500 feet. Whether that aircraft's greater noise impact will significantly increase the problem of community acceptance is an important trade-off question which also merits further study.

QCSEE Engine Studies

Two parallel engine studies, sponsored by the NASA-Lewis Research Center, were coordinated with the two STOL system studies discussed previously. These studies, designated "quiet, clean, STOL, experimental engine studies (QCSEE) were conducted by Detroit Diesel Allison Division of General Motors and the General Electric Company.

The main objectives of the QCSEE studies were to identify the characteristics of engines and propulsion systems for anticipated STOL aircraft to provide data for the STOL systems studies and to define the engine concept and cycle that would be developed as a demonstrator engine later in the QCSEE program.

Stringent noise and pollution constraints were imposed in the QCSEE studies. In lieu of specific STOL aircraft noise regulations, which have not been established, the noise goal for a four-engine STOL aircraft was set as follows: 95 EPNdB along a 152 m (500 ft) sideline at 80 knots forward speed after liftoff and takeoff power setting. For EBF aircraft, this constraint included the noise from the interaction of the jet and flaps, and for AW aircraft, the constraint included the noise associated with the wing augmentor. Pollution level constraints are outlined below.

Pollutant	Critical operating condition	Typical 1972 levels, g/kg fuel	QCSEE goals, g/kg fuel
Hydrocarbons	Idle	7-55	8
Carbon monoxide	Idle	30-77	40
Oxides of nitrogen	Takeoff	13-40	12[a] 12[b]
Smoke	Takeoff	20-65	15[c]

[a]Engine pressure ratio = 18
[b]Engine pressure ratio = 30
[c]Based on SAE ARP 1179

These noise and pollution constraints provide a significant improvement over present-day emission levels. The exhaust pollution constraints are considered realistically attainable through modern combustor design. However, it has been demonstrated in the STOL systems studies that the noise goal, although attainable, results in significant penalties in the design and economics of the aircraft. More discussion of the sideline noise requirement and its relationship to the noise "footprint" is given in the section on Aircraft.

The matrix of engines submitted by the QCSEE contractors to the STOL systems study contractors covered a range of cycle parameters for each of the STOL aircraft concepts as outlined below.

Lift systems	Fan pressure ratio	Total pressure ratio	Turbine inlet temperature, °K (°F)
EBF			
VP/G	1.15:1.25	20	1589 (2400)
FP/G	1.20:1.50	15:25	1478 (2200) - 1922 (3000)
FP/D	1.30:1.50	20	1589 (2400)
OTW			
VP/D	1.25	17	1589 (2400)
FP/G	1.20:1.50	20	1589 (2400)
FP/D	1.30:1.39	17:30	1478 (2200) - 1922 (3000)
AW2S			
FP/G	1.50	20	1589 (2400)
FP/D	1.50:3.00	15:25	1478 (2200) - 1922 (3000)
AW3S			
VP/G	1.50:3.00[a]	20	1478 (2200) - 1922 (3000)
FP/D	3.00	17:25	1589 (2400)

[a]Pressure ratio to the wing

The nomenclature in the above table is defined by:

MF	mechanical flap	VP	variable-pitch fan blading
EBF	externally blown flap	FP	fixed-pitch fan blading
OTW	over the wing	G	gear-driven fan
AW2S	augmentor wing - two stream engine	D	direct-drive fan
AW3S	augmentor wing - three stream engine		

Each engine was configured with a nacelle having sufficient acoustic treatment in the inlet and exhaust ducts to meet the noise goal. Additional data were provided at 90 and 100 EPNdB at 152 m (500 ft) sideline. To configure propulsion systems for MF aircraft, the STOL systems study contractors used either the EBF or OTW engines previously listed. The three-stream engine for the AW offers no advantage over the two-stream engine, and since the required engine would be a complex and unique design, this concept was deleted from final consideration during the course of the aircraft studies.

The results of the STOL systems studies identified the following engine cycles as being best suited for each of the STOL aircraft concepts:

Concept	EBF	OTW	AW2S	MF
Design	VP/G	FP/G	FP/D	FP/G
Fan pressure ratio	1.25:1.30	1.30:1.35	3.0	1.35:1.40
Bypass ratio (approx.)	18:14	14:12	2.8	12:10.5
Total pressure ratio	15:20	15:20	20	15:20
Turbine inlet temperature, °K (°F)	1589 (2400)	1589 (2400)	1589 (2400)	1589 (2400)

The sensitivity to total pressure ratio and turbine inlet temperature in the ranges investigated was minor compared to the fan pressure ratio. Thus, it is believed that existing advanced core gas generators can be used in the eventual design of the QCSEE demonstrator engine (e.g., the General Electric F-101 core or the Allison GMA 100 core).

General Electric did not include specific conclusions in its final report.

The conclusions of the Allison study are:

- The two EBF under-the-wing propulsion systems studied (PD287-5 and -7) will meet the 95-EPNdB STOL aircraft noise goal.
- The two EBF over-the-wing propulsion systems studied (PD287-6 and -11) will meet the 95-EPNdB STOL aircraft noise goal.
- The one augmentor wing propulsion system studied (PD287-51) will meet the 95-EPNdB STOL aircraft noise goal.
- Each of the five propulsion systems studied will meet the NASA pollution standards.

- Additional acoustic development is required to fully substantiate the acoustic designs presented.

- Additional propulsion system-aircraft development testing is required to establish the STOL propulsion system-wing-aircraft interaction noise, aerodynamics, and control.

Although the two engine contractors are not in complete agreement on all details of engine design, the differences are indicative of differences in design philosophy, not technology requirements. It is apparent that no new untried materials technology is required to meet the design objectives of the QCSEE engine designs.

Part II. COMPARATIVE EVALUATION OF SHORT HAUL STUDIES

In this section, the short haul studies described in Part I are compared to NASA results and evaluated with respect to short-haul markets, aircraft characteristics, economic implications, and technology needs. The impact of fuel conservation was not specifically treated in any of these studies. However, as a result of the concern for fuel conservation generated by recent fuel shortages, a study was initiated with the Lockheed Aircraft Corporation as an extension of their STOL systems study (described earlier) to investigate the effects on aircraft design of optimizing for minimum fuel consumption and for higher fuel prices. The results of this study are reported in reference 9.

Short-Haul Markets

The short-haul studies considered in this review assumed different operating characteristics and consequently provided different market and demand projections. It is convenient to relate these studies to types of airports recently proposed by the FAA; namely,

Type 1. Segregation of short- and long-haul operations at an existing airport using existing short and long runways, or through the addition of new short STOL runways.

Type 2. Diversion of short-haul operations to secondary airports that now have little or no scheduled air carrier service.

Type 3. Selection of one airport in a multiairport terminal area to serve predominantly or exclusively short-haul STOL traffic.

Type 4. Construction of new short STOL landing facilities near the center of metropolitan areas or near peripheral high-density areas.

The Aerospace Corporation study considered airport types 1, 2, and 4, but emphasized type 2 in order to maximize congestion relief at hub airports. Connecting passengers, who were not modeled in the Aerospace study, would continue to be served at type 1 airports. The Douglas study also considered airport types 1, 2, and 4, but emphasized type 1 in order to provide service to connecting passengers and to minimize community objections to new service at additional airports. Lockheed considered types 1 and 3. The Stanford STOL study considered types 1, 2, and 4. (The Boeing/Wichita study did not consider airports or markets so it will not be considered further here.)

The following subsections compare these studies in their approach to analyzing passenger demand networks, number of aircraft required, congestion, airports, and community acceptance.

Demand analysis– Douglas extrapolated historical CAB origin and destination (O&D) data to 1985 using four different techniques for curve fitting: linear, geometric, exponential smoothing, and polynomial trend fitting. The historic average annual growth rate was computed for each of these techniques for each of the top 1,000 city pairs. These derived growth rates were compared with the historical growth rates and judgement was applied to determine the most suitable growth rate through 1985. The city pairs having more than 300,000 annual O&D passengers (for city pairs less than 600 miles apart) provided the basis for the STOL systems study. The average growth for all the city pairs from 1970 to 1985 was 8 percent compounded annually. The 1970 CTOL traffic was assumed to be a base for future CTOL and was allowed to expand by 2 percent a year, reflecting the fact that not all U.S. city pairs are affected by congestion. The balance of this estimated passenger growth, or 6 percent per year, was arbitrarily assigned to the STOL system. Figure 1 illustrates the demand as estimated by Douglas.

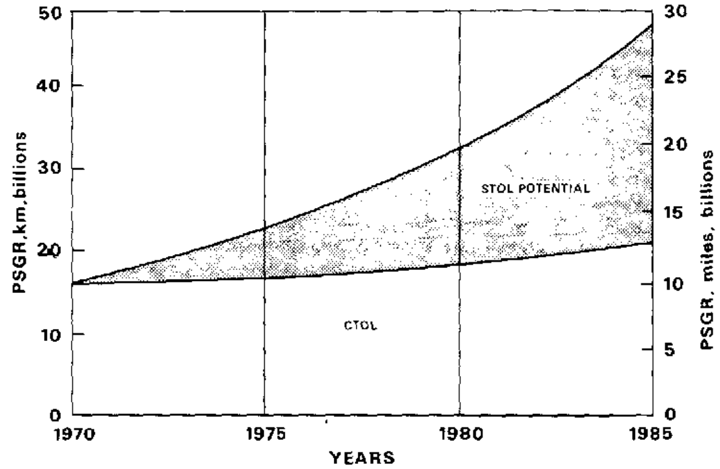


Figure 1.– U.S. short-haul passenger demand (Douglas).

Lockheed simulated future operations of an existing airline and did not attempt to estimate total demand; instead, the 1971 CAB O&D survey of passengers on the airline network was used as a base. Extrapolation of this traffic data base from 1971 to the 1980-1990 time frame for Eastern Airlines was accomplished using the growth rates as presented in table 1. Lockheed also simulated

TABLE 1.– EASTERN AIRLINES DEMAND GROWTH FACTORS (LOCKHEED)

Region	Demand growth factors			Equivalent compounded growth rate, percent
	1980	1985	1990	
NE Corridor	1.71	2.19	2.76	5.5
FLA – ATL – SE NY – MidW NE – FLA MidW – FLA	2.17	3.15	4.44	8.0
SE – ATL	2.35	3.52	5.13	8.9
MidW – ATL	2.50	3.80	5.58	9.6
ATL – TEX TEX – FLA	2.55	3.92	5.81	9.8
NE – ATL	2.65	4.08	6.12	10.2
NE – TEX	2.70	4.24	6.48	10.5
Semi Transcon	2.85	4.58	7.19	11.0

operations for Allegheny Airlines, but took a somewhat different approach because growth rates have stabilized in the Northeast and because differences in growth rates among the city pairs in this area are minimal. Uniform growth rates were applied to all the city pairs for potential STOL introduction by Allegheny. Table 2 lists the major differences between the two approaches.

TABLE 2.– EASTERN AND ALLEGHENY SYSTEMS SIMULATIONS

	EAL	AL
Growth rate	Per route	Constant, uniform (7, 8, 9%)
Fleet	Twin, B727-200, STOL	Twin, DC9-30, STOL
Service	Mixed (Twin, 727) All Coach (STOL)	All Coach
STOL Flight Assignment	Congestion Relief/ Economic (100%)	Congestion Relief (30%)
Area Coverage	Interregional (Northeast/Southeast)	Intraregional (Northeast)

The Aerospace Corporation estimated total intercity travel demand (for all modes, including STOL and CTOL) and then used a Monte-Carlo modal-split model to determine the demand for STOL, based on a least cost to the traveler algorithm. Total demand was estimated using a model that assumes that changes in intercity travel demand from the base year to the test year can be measured by changes in the product of the populations of the origin and destination regions. Aerospace projected the demand only for the 15 city pairs that constituted the STOL network.

The Stanford study was limited to the California Corridor. A gravity model was developed for projecting future traffic between San Francisco and Los Angeles areas. These demands were then split among the various modes (STOL, CTOL, auto, bus, etc.) according to a least-cost-to-the-traveler algorithm. The Stanford approach was very similar to the Aerospace approach but much more limited in scope.

STOL Networks– Different market scenarios were adopted by each contractor. As shown in figure 2, Douglas studied six mainland regions and one offshore – Hawaii. The mainland regions were the Northeast Corridor, Chicago area, California Corridor, Southern, Southeast, and Northwest regions. In each case, Douglas assumed the operation of the STOL system as a separate division of an existing airline. There were 96 city pairs which formed the nationwide STOL system. Figure 3 shows the routes and city pairs analyzed by Douglas.

Lockheed, on the other hand, analyzed part of the Eastern and Allegheny Airlines route systems to determine where STOL aircraft might be appropriately used. Thus, the results are not directly comparable to the other studies because the regions were mixed from Southeast to Northeast to Midwest. Figure 4 illustrates these route systems. The heavy lines indicate that part of the Eastern system in which STOL aircraft would be utilized. As can be seen the Eastern system covered parts of the Northeast, Southeast, and the Southern regions considered by Douglas. Allegheny selected the routes most likely to form the network over which they would introduce

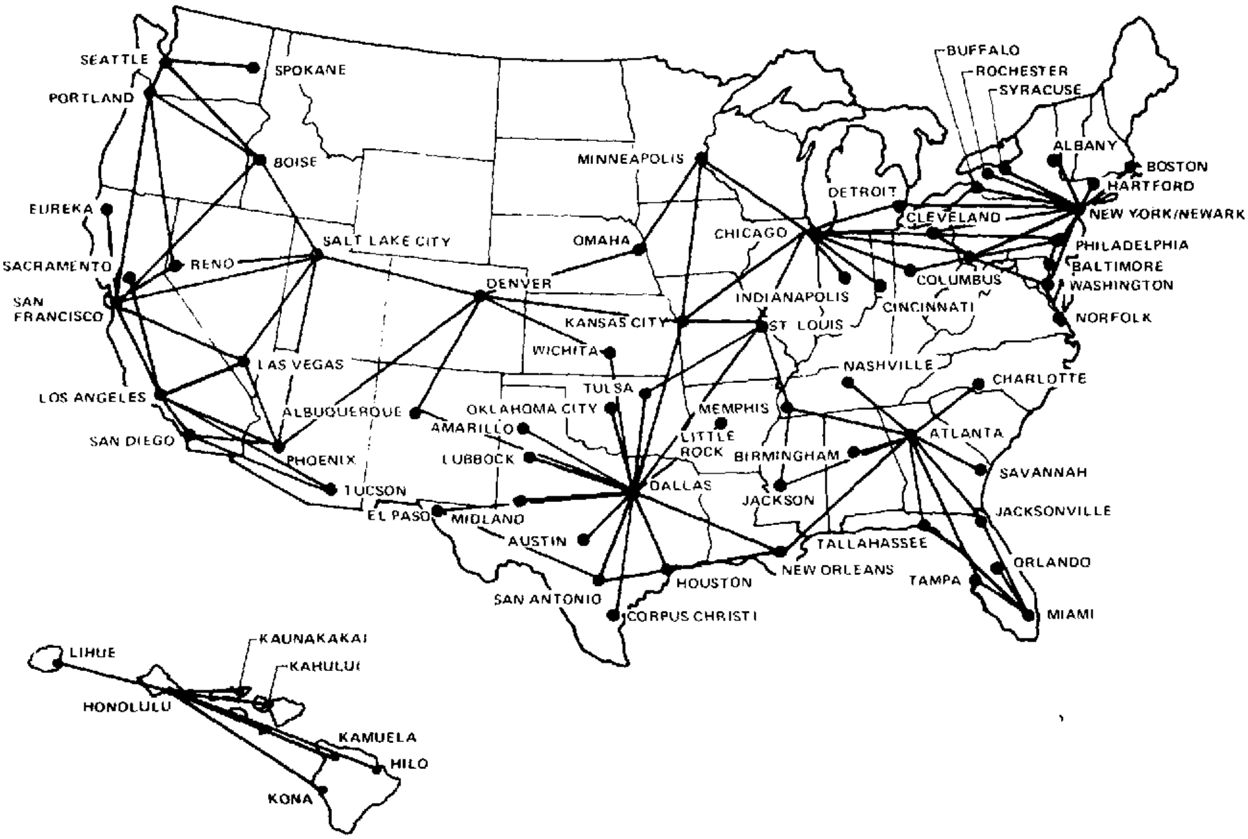
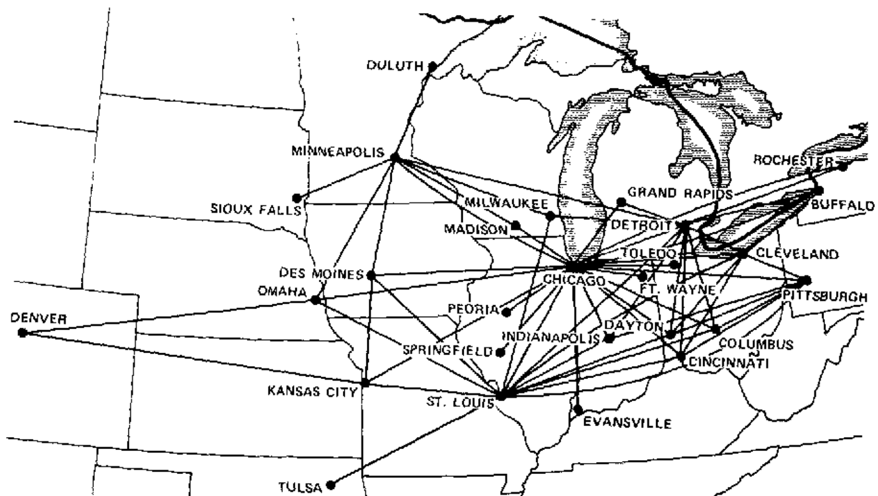
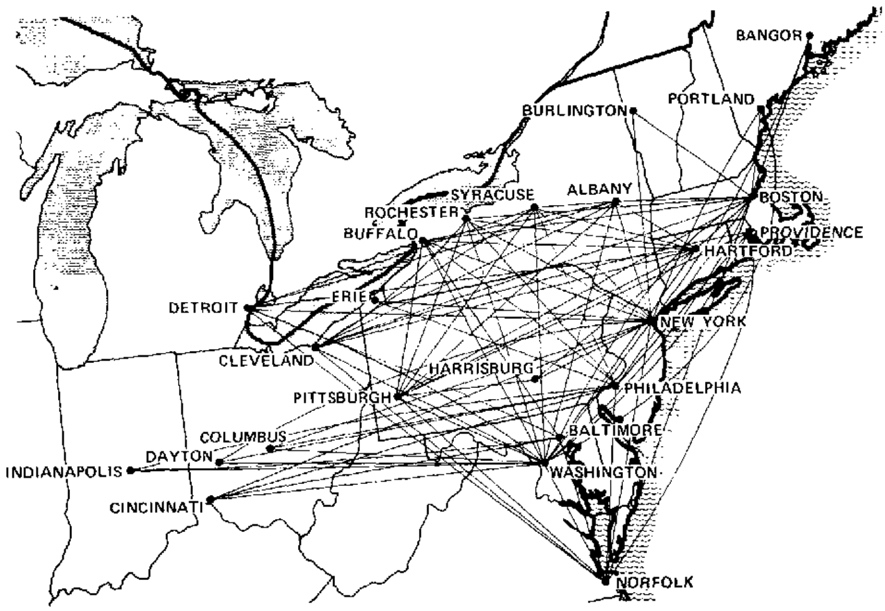


Figure 2.– Representative short-haul market regions (Douglas).



(a) Chicago region

Figure 3.– Regional STOL networks (Douglas).



(b) Northeast region

(c) California region

Figure 3.– Continued.

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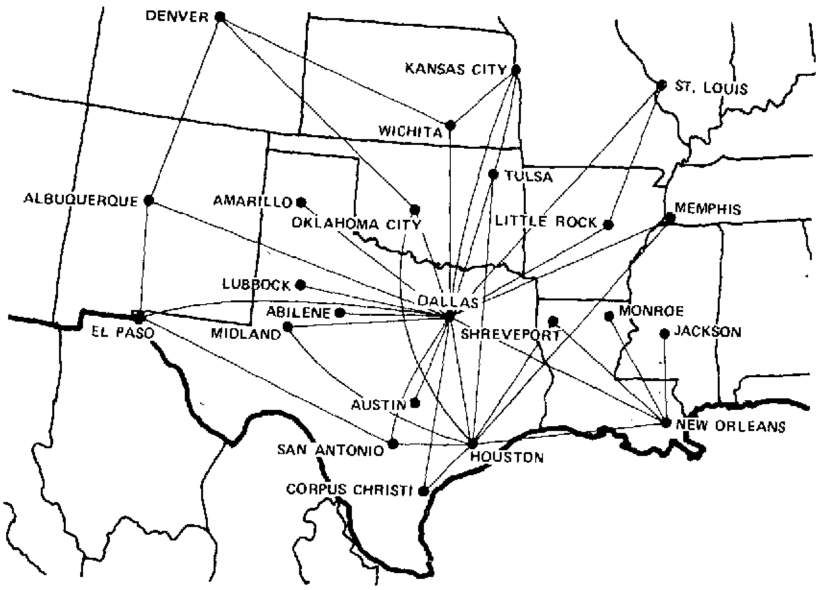
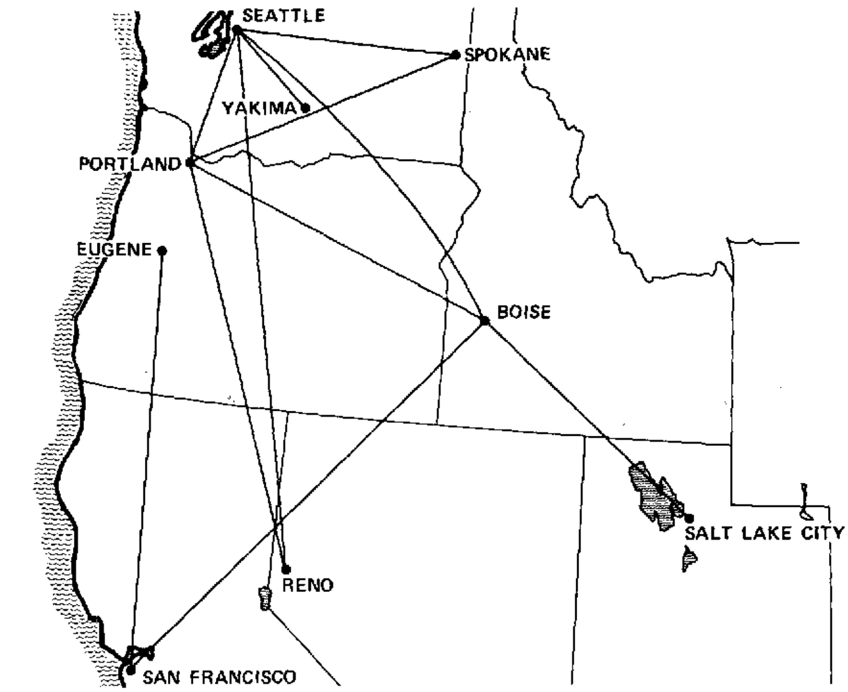


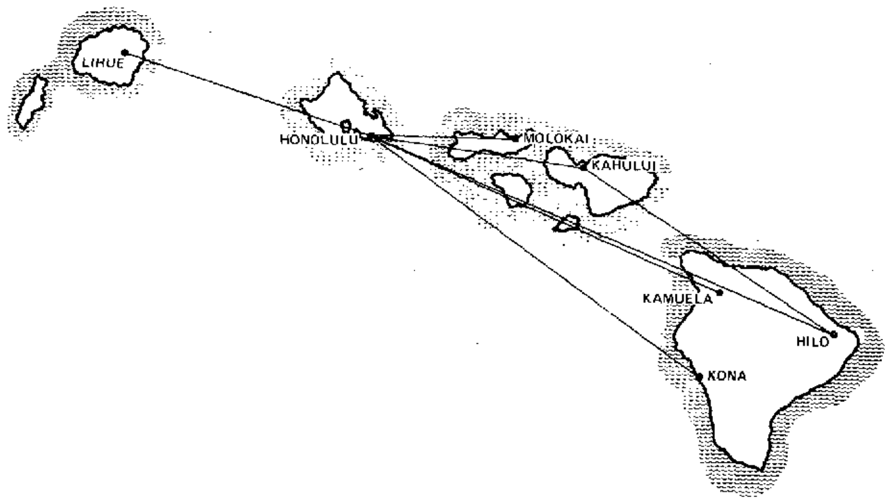
(d) Southern region

(e) Southeast region

Figure 3.– Continued.

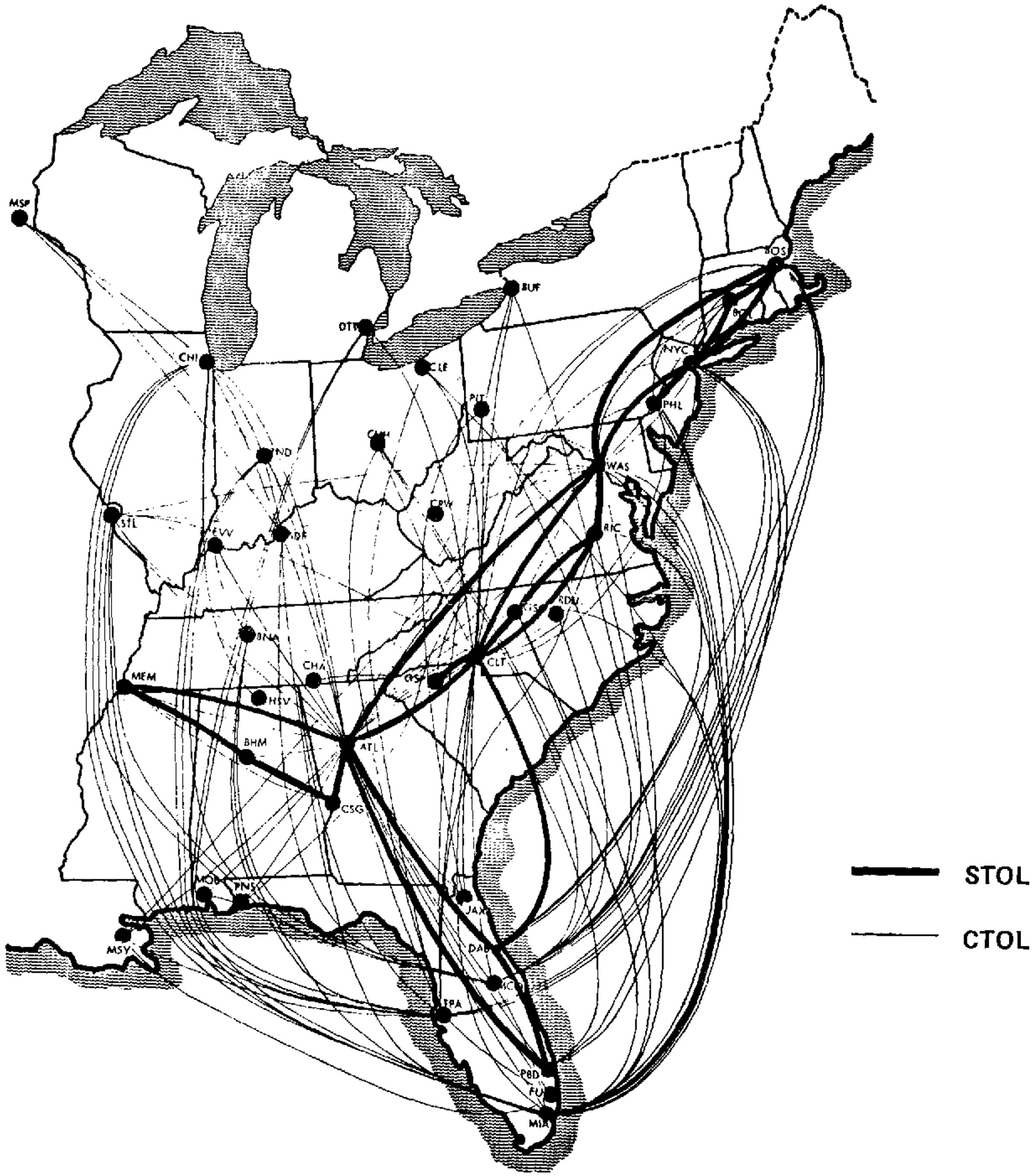


(f) Northwest region



(g) Hawaii region

Figure 3.– Concluded.



(a) Eastern Airlines

Figure 4.– Airline STOL networks (Lockheed).

(b) Allegheny Airline

Figure 4.– Concluded.

STOL aircraft. Scheduling and flight assignment for STOL was based on relieving 30 percent of the Allegheny flights at congested hubs.

Aerospace studied the market in the Northeast Corridor, the Chicago area, and the California Corridor. They assumed the operation of a single transportation system operating freely in competition with existing airlines similar to PSA in the California Corridor, but with regulatory freedom to cross state lines. The systems connecting the 15-city pairs are shown in figure 5. It should be noted that these were more limited networks than the Douglas and Lockheed studies.

The Stanford study was limited to the California Corridor, specifically between Greater Los Angeles and the San Francisco Bay area.

STOL aircraft demand– All the contractors agreed that a configuration with about 150 passengers was the optimum size for the STOL systems they studied, but the wide divergence of those systems makes it difficult to compare total fleet demands; in fact, Stanford and Lockheed did not make estimates of total demand for STOL aircraft. The Aerospace Corporation's study of systems configured to yield an 8 percent ROI gave the following fleet sizes: California, 14; Midwest, 6; and Northeast, 32. If the aircraft were designed with extended range potential to permit operation between Chicago and New York, the requirement for 24 additional aircraft was determined. Based on earlier studies by Aerospace Corporation, they then estimate total U.S. fleet to be something less than 300 in the 1980s.

The Douglas study estimated that 240 aircraft would be required by 1985 and 320 by 1990. These are for short-haul systems of less than 965 km (600 mi). If the aircraft were extended in range to 1447 km (900 mi), these numbers rise to 357 in 1985 and 500 in 1990. If stage segments up to 1930 km (1200 mi) are included, the market more than doubles to 535 in 1985 and 715 in 1990. Douglas additionally estimated the foreign STOL civil market for 1985 at 320 and for 1990 at 545, for 965 km (600 mi) or less stage lengths. This foreign market estimate is based on Douglas' estimate of non-U.S. traffic growth rates of 9.6 percent between 1971 and 1985. The 1971 base level of passenger traffic was assigned to CTOL and allowed to expand at a rate of 4 percent per year. The remainder of the growth, or 5.6 percent, was assigned to STOL. These estimates apparently are made without due consideration for the individual airports and communities involved and therefore may be considered optimistic.

Congestion relief– Lockheed proposed to relieve the hub air congestion in the major multi-airport hubs by diverting all O&D short haul to a converted STOL-only airport. Figure 6 illustrates the resultant capacity improvement for the New York hub. For single-airport hubs, capacity improvement was provided by adding new STOL runways. Douglas estimates of congestion relief afforded by STOL are shown in table 3 and Aerospace's estimates are shown in table 4.

Although these studies agree that provision of separate facilities (and airspace) for short-haul O&D traffic can relieve airside congestion at hub airports, many factors affecting congestion, such as ATC considerations, terminal crowding, and inadequate airport ground access, were not considered in sufficient depth for a definitive assessment in this regard. In addition, further studies are required to determine the impact of separate airspace allocation for short-haul aircraft. Nevertheless, on the basis of these preliminary results, it would appear that STOL aircraft systems at least have the potential to relieve possible future airside congestion.

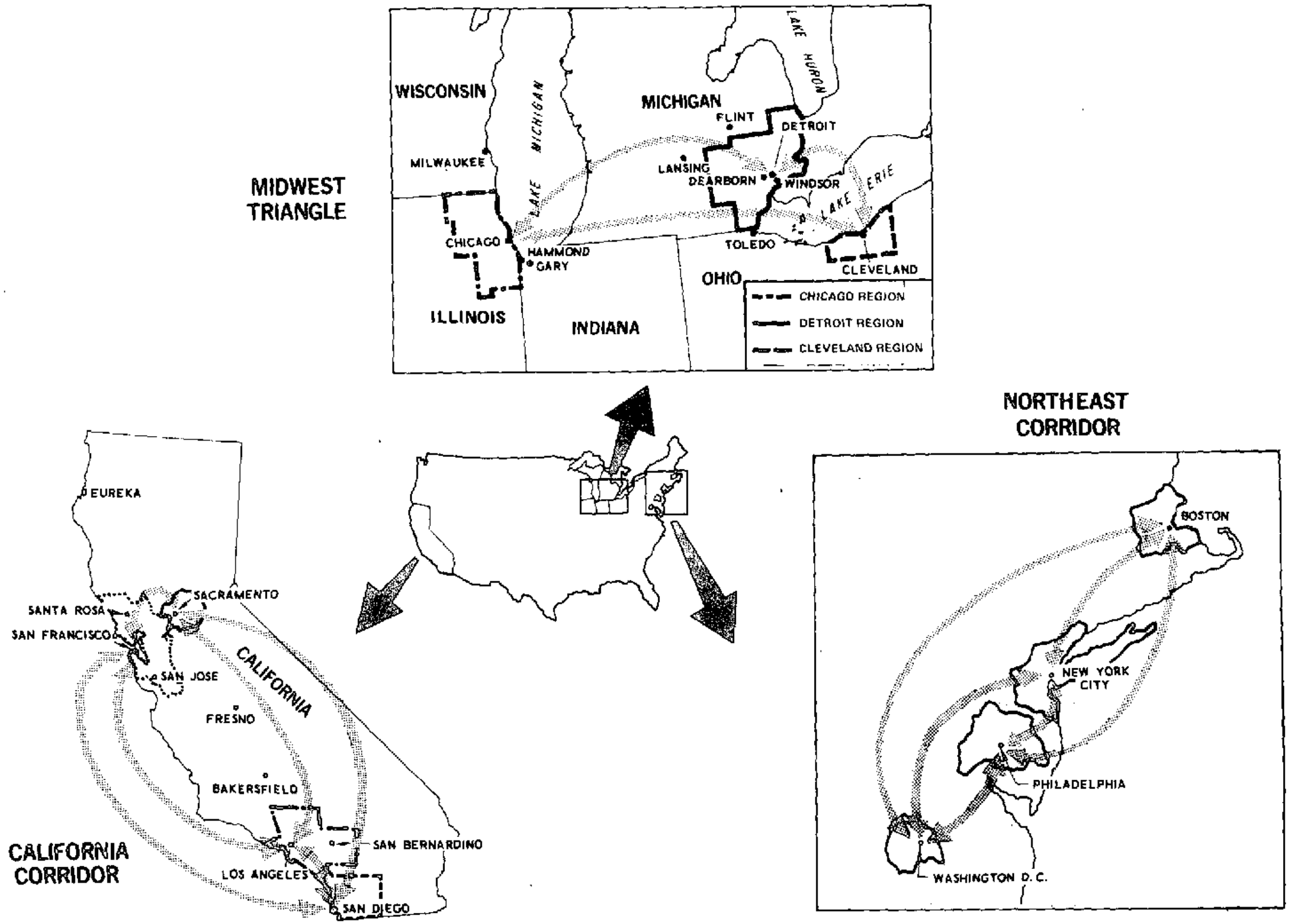


Figure 5.– Aerospace STOL networks.

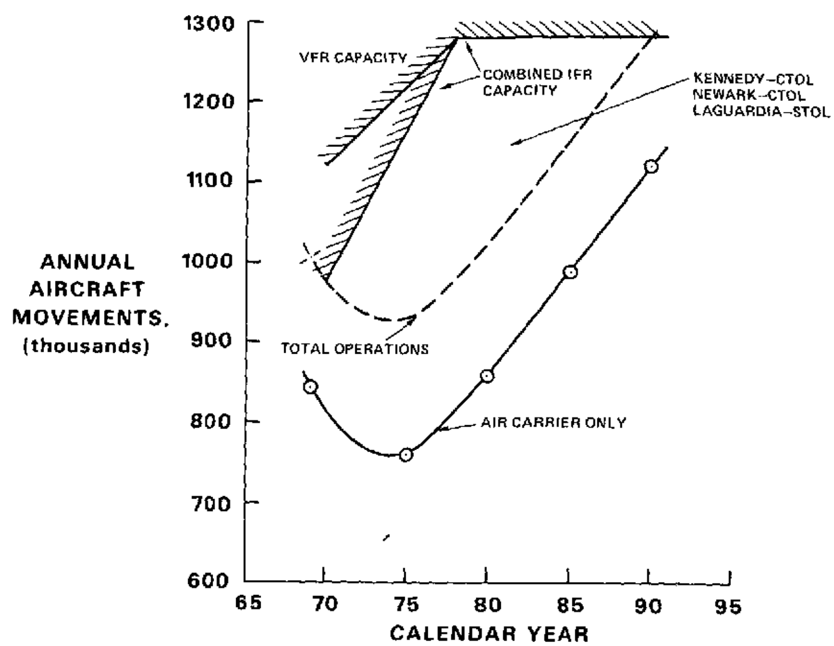


Figure 6.– New York metropolitan hub capacity forecast (Lockheed).

TABLE 3.– DOUGLAS AIRPORT CONGESTION RELIEF

(Selected hubs – annual operations)

Airport	Total aircraft movements (000)	STOL O&D short haul passengers (000)	STOL aircraft movements (000)	Aircraft movements reduced (percent of total)
Chicago O'Hare	1,206	12,700	141	11.7
Atlanta International	725	9,605	107	14.8
Detroit Metropolitan	444	6,552	73	16.3
Philadelphia International	409	5,605	62	15.2
St. Louis Lambert	330	4,827	54	16.4

Airports– Table 5 compares the airports selected for each city where the individual contractor's networks coincide. The general consensus as to airport site selection should be noted. The exceptions result from the contractor's desire to emphasize different types of airports – for example, Lockheed's conversion of La Guardia and Washington National to dedicated STOLports and Aerospace's use of general aviation airports in the Washington area. Only in New York, Los Angeles, and San Francisco were new STOLports considered; none were considered by Lockheed. The consensus of the studies is that in almost every case there is a close-in airport with adequate runway length for STOL service. Thus, on the basis of these studies, there seems to be no compelling reason to require less than 914 m (3000 ft) runway length to provide airside congestion relief.

TABLE 4.– EFFECT OF STOL SERVICE INTRODUCTION ON CTOLport CONGESTION (AEROSPACE)

Airport	1980 CTOL forecast (without STOL)	Reduction due to STOL diversion	Cost saving ($)	Equivalent delay in construction (years)	Reduction due to STOL diversion	Cost saving ($)	Equivalent delay in construction (years)
Los Angeles (LAX)							
Passengers (enplane and deplane)	35,000,000	1,780,000		0.9	4,475,000		2.7
Parking requirements (spaces)	14,481	594	1,190,000		1,622	3,244,000	
Gate requirements	73	3	300,000		8	800,000	
San Francisco (SFO)							
Passengers (enplane and deplane)	25,000,000	2,100,000		1.4	4,350,000		3.0
Parking requirements (spaces)	10,870	776	1,552,000		1,705	3,410,000	
Gate requirements	56	4	400,000		8	800,000	
O'Hare (ORD)							
Passengers (enplane and deplane)	60,000,000	1,300,000		0.4	1,340,000		0.4
Parking requirements (spaces)	17,708	391	782,000		462	924,000	
Gate requirements	131	3	300,000		3	300,000	
La Guardia (LGA)							
Passengers (enplane and deplane)	24,000,000	4,150,000		3.3	4,615,000		3.7
Parking requirements (spaces)	9,239	1,386	2,772,000		1,571	3,142,000	
Gate requirements	60	8	800,000		10	1,000,000	

TABLE 5.– COMMON AIRPORTS

City	Study Contractors: Douglas	Lockheed	Aerospace	Stanford
(a) Northeast				
New York	Secaucus Westchester Islip	La Guardia	Secaucus Westchester Mitchell	
Boston	Norwood Bedford	Logan	Logan Bedford	
Philadelphia	North Phil.	Phil.	North Phil.	
Washington	National	National	College Park Prince Georges	
(b) Mid West				
Chicago	Meigs Field Midway		Meigs Field	
Cleveland	Lakefront		Lakefront	
Detroit	Detroit City		Detroit City Mettetal	
(c) California Corridor				
Los Angeles	Patton Orange City El Monte Long Beach Van Nuys		Patton Fullerton	Patton Santa Monica El Monte Long Beach Van Nuys Burbank
San Francisco	Moffett Field Oakland Reid Hillview		Palo Alto India Basin	Palo Alto India Basin San Jose San Francisco Hayward San Carlos Buchanan
San Diego	Montgomery		Montgomery	

Community acceptance– One of the reasons for Lockheed's decision to concentrate on existing CTOL airports for STOL service was their understanding of the widespread opposition to construction of new airports or expansion of service at existing airports. Their proposed conversion of La Guardia, Midway, and Washington National to all-STOL airports may well offer some community relief from aircraft noise in the immediate vicinity of these airports.

Aerospace based their acceptability criteria for noise on the FAA's recommendation of 30 NEF as a level of acceptability. On that basis, their studies show little noise impact on the surrounding community; however, they recognize the difficulty of implementing new airports. Since that study was initiated, serious doubts in government and industry have arisen as to the use of NEF contours as a measure of acceptability. As a result, the Aerospace conclusions that STOL would be acceptable must be considered in context with the assumption of 30 NEF acceptability.

The Douglas and Stanford studies both considered community acceptance to a much greater degree than did the others although neither study was sufficiently comprehensive to define all aspects of the problem. Both interviewed community leaders and airport officials with regard to acceptability of new airports or new services at existing airports. These interviews indicate that the potential adverse impacts of STOL would be extremely controversial. Both Stanford and Douglas emphasize the need for vastly expanded research in "community acceptance analysis." Lockheed and Aerospace highlight the need for further study and better understanding of aircraft noise and environmental impact. Douglas and Lockheed did indicate that general aviation airports located in growth-oriented communities in the urban periphery may have potential for development as individual additions to the existing system, improving service or relieving congestion at hub airports. It should be emphasized that each airport must be considered separately as a distinct case study in acceptability.

Aircraft Analysis

The various studies under consideration treated a wide variety of short-haul aircraft concepts at different levels of detail in the design analysis. The studies by Douglas and Lockheed provide the broadest coverage of lift concepts and the most detailed design information on the vehicles. The Boeing/Wichita study considered only the EBF and MF lift concepts and the level of detail was that typical of a parametric design analysis. The guidelines for the Aerospace and Stanford studies did not include aircraft design. In these latter studies, representative short-haul designs were employed to perform the economic, operational, and market analyses. Aerospace analyzed an augmentor wing concept with a 610 m (2000 ft) field length capability. The Stanford analysis utilized the Douglas EBF configurations having 610 and 914 m (2000 and 3000 ft) field length capabilities.

Aircraft characteristics– The market portions of all the various studies indicated that an aircraft sized for approximately 150 passengers is the preferred size for high-density markets. Therefore, the comparisons in this section will consider only this size of aircraft.

Table 6 summarizes the general characteristics of various 150-passenger designs by lift concept, contractor consideration, and design field length. Since the Aerospace study used the noise characteristics developed in reference 10, which was a detailed design analysis performed by Boeing/Seattle of the augmentor wing concept, table 6 also lists the general characteristics of this

TABLE 6.– AIRCRAFT CHARACTERISTICS – 150 PASSENGERS

Characteristics \ Contractors	Lift concept							
	EBF					MF		
	Douglas	Lockheed	Boeing Wichita	Douglas	Lockheed	Douglas	Lockheed	Douglas
Design field length, m (ft)	914 (3000)	914 (3000)	762 (2500)	610 (2000)	610 (2000)	1219 (4000)	1219 (4000)	914 (3000)
Engine technology	QCSEE	QCSEE	CF6-TF39	QCSEE	QCSEE	QCSEE	QCSEE	QCSEE
Takeoff gross weight, kg (lb)	74,073 (163,300)	66,529 (146,669)	76,114 (167,800)	93,532 (206,200)	83,004 (182,989)	69,877 (154,050)	62,120 (136,948)	80,877 (178,300)
Operating weight empty, kg (lb)	51,597 (113,750)	44,240 (97,531)	50,667 (111,700)	68,902 (151,900)	58,037 (127,947)	48,045 (105,920)	40,509 (89,305)	58,188 (128,280)
Wing area, m^2 (ft^2)	152 (1633)	145 (1563)	215 (2314)	288 (3100)	231 (2483)	142 (1525)	136 (1462)	225 (2426)
Wing loading, kg/m^2 (lb/ft^2)	487 (100)	459 (93.8)	354 (72.5)	325 (66.5)	359 (73.7)	492 (101)	457 (93.7)	359 (73.5)
Rated thrust/engine, kg (lb)	9648 (21,270)	9211 (20,306)	9027 (19,900)	12,170 (26,830)	13,241 (29,191)	15,599 (34,390)	15,331 (33,798)	15,803 (34,840)
Number of engines	4	4	4	4	4	2	2	2
Thrust loading	0.521	0.554	0.474	0.520	0.638	0.446	0.494	0.391
152 m (500 ft) sideline noise, EPNdB	95	91.8	126	95	93.7	95	92.5	95
Area 95 EPNdB contour, km^2 ($mi.^2$)	0.541 (0.209)	0.321 (0.124)	61.41 (23.71)	0.412 (0.159)	0.466 (0.180)	0.671 (0.259)	0.479 (0.185)	0.518 (0.200)
Cruise speed, Mach	0.68	0.80	0.80	0.68	0.80	0.76	0.80	0.72
Cruise altitude, m (ft)	7620 (25,000)	9144 (30,000)	10,668 (35,000)	7620 (25,000)	9144 (30,000)	7925 (26,000)	9144 (30,000)	8534 (28,000)
Range, km (n.mi.)	926 (500)	926 (500)	3-463 hops (3-250)	926 (500)	926 (500)	926 (500)	926 (500)	926 (500)

TABLE 6.– AIRCRAFT CHARACTERISTICS – 150 PASSENGERS (Concluded)

	Lift concept								
	MF		AW				OTW		OTW/IBF
Characteristics / Contractors	Lockheed	Boeing Wichita	Douglas	Lockheed	Aerospace	Boeing Seattle	Douglas	Lockheed	Lockheed
Design field length, m (ft)	914 (3000)	762 (2500)	610 (2000)	610 (2000)	610 (2000)	610 (2000)	610 (2000)	914 (3000)	914 (3000)
Engine technology	QCSEE	CF6-TF39	QCSEE	QCSEE	QCSEE	STF-395D*	QCSEE	QCSEE	QCSEE
Takeoff gross weight, kg (lb)	76,608 (168,888)	67,269 (148,300)	95,832 (211,270)	88,774 (195,710)	64,766 (142,782)	90,053 (198,530)	105,616 (232,840)	61,858 (136,372)	66,837 (147,349)
Operating weight empty, kg (lb)	52,590 (115,939)	43,772 (96,500)	66,820 (147,310)	61,971 (136,620)	39,610 (87,324)	63,989 (141,070)	80,106 (176,600)	40,000 (88,183)	44,568 (98,253)
Wing area, m^2 (ft^2)	252 (2710)	246 (2648)	230 (2471)	223 (2400)	166 (1785)	228 (2451)	361 (3881)	128 (1375)	146 (1571)
Wing loading, kg/m^2 (lb/ft^2)	304 (62.3)	273 (56)	417 (85.5)	398 (81.5)	390 (80)	395 (81)	293 (60)	483 (99.2)	458 (93.8)
Rated thrust/engine, kg (lb)	19,936 (43,951)	6963 (15,350)	10,070 (22,200)	9253 (20,400)	6940 (15,300)	9021 (19,888)	12,465 (27,480)	7777 (17,145)	16,697 (36,811)
Number of engines	2	3	4	4	4	4	4	4	2
Thrust loading	0.520	0.310	0.420	0.417	0.43	0.401	0.472	0.503	0.50
152 m (500 ft) sideline noise, EPNdB	----	112	95	93.4	90	89	95	93.8	95.3
Area 95 EPNdB contour, km^2 ($mi.^2$)	----	9.06 (3.5)	0.412 (0.159)	0.572 (0.221)	0.174 (0.067)	----	0.440 (0.170)	0.684 (0.264)	0.603 (0.233)
Cruise speed, Mach	0.80	0.80	0.79	0.8	0.8	0.8	0.7	0.8	0.8
Cruise altitude, m (ft)	9144 (30,000)	10,668 (35,000)	8839 (29,000)	9144 (30,000)	9144 (30,000)	9144 (30,000)	9144 (30,000)	9144 (30,000)	9144 (30,000)
Range, km (n.mi.)	926 (500)	3-463 hops (3-250)	926 (500)	926 (500)	806 (435)	926 (500)	926 (500)	926 (500)	926 (500)

*Pratt & Whitney conceptual engine – mid-1970 technology.

configuration. Design field lengths were based on 35° C (95° F) ambient temperature at sea level conditions except for the Boeing/Wichita designs which were for standard day temperature at sea level. The engine technology was based on the QCSEE program for all designs except the two Boeing studies. Boeing/Wichita used technology of the General Electric CF6-TF39 family and Boeing/Seattle the technology of a conceptual Pratt and Whitney engine for the mid-1970s.

The Douglas and Lockheed studies had a design sideline noise goal of 95 EPNdB at 152 m (500 ft) as a guideline. The Boeing/Wichita study did not have a noise constraint specified. In all cases shown in table 6, the size of the 95 EPNdB contour reflects essentially the noise characteristics of the source since the operational profiles of the vehicles are similar for a given field length. This will be discussed in more detail later.

The design range for all concepts was 924 km (500 nm) except for the Boeing/Wichita and Aerospace studies. Boeing designed for three 462 km (250 nm) stages without refueling, whereas Aerospace considered a design range of 804 km (435 nm).

The Douglas designs in table 6 are those referred to by Douglas as the "system analysis designs" and are the ones used in this comparative analysis since they were the only designs for which Douglas made a detailed noise and economic analysis. Douglas also derived "final design" aircraft in their analysis, but insufficient noise and economic parametric information was developed.

During the conduct of the Douglas and Lockheed Systems studies, the Systems Studies Division (SSD) at Ames Research Center performed independent in-house analyses of certain aspects of the EBF and MF designs considered in the contractual studies. Where appropriate, the results of this in-house effort are included for comparative purposes.

Figure 7 shows the trend in gross weight with field length for the aircraft analyzed in the various studies. The powered-lift concepts are shown on the left and the unpowered on the right. Douglas and Lockheed designs are represented by the shaded band. Within this band, the Douglas designs are generally heavier for a given field length capability. The SSD in-house analysis of the weights of the 914 m (3000 ft) EBF and 1220 m (4000 ft) MF designs of Douglas and Lockheed are also shown. In this latter analysis, the geometric shape and thrust requirement as determined by the contractors was used along with current SSD weight estimating techniques to determine weights of the four configurations. The results are shown by the solid bars for field length capability of 914 m (3000 ft) for the EBF and 1220 m (4000 ft) for the MF. On a comparative basis, it appears the Lockheed weights are slightly optimistic and the Douglas weights are slightly conservative with respect to the SSD in-house results.

The Boeing/Wichita weights shown in figure 7 represent vehicles that were not acoustically treated to meet a specified noise criteria, as mentioned earlier. Therefore, it would be expected that these weights would be somewhat lower than the Douglas and Lockheed designs. It will be noted that the EBF weights are very similar to the powered-lift concepts of Douglas and Lockheed while the MF weights are considerably lower. The lower thrust requirement of the Boeing MF (fig. 8) is a contributing factor to the lower MF weights, while the lower wing loadings (fig. 9) for Boeing's EBF design are primarily responsible for the EBF weights being comparable to the Douglas and Lockheed EBF weights despite the greater acoustic treatment of the latter two.

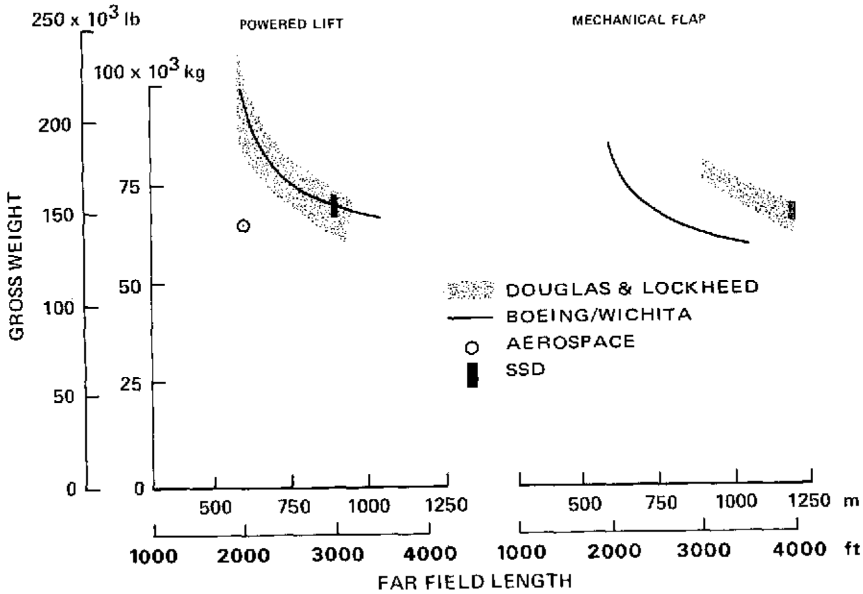


Figure 7.– Gross weight comparisons.

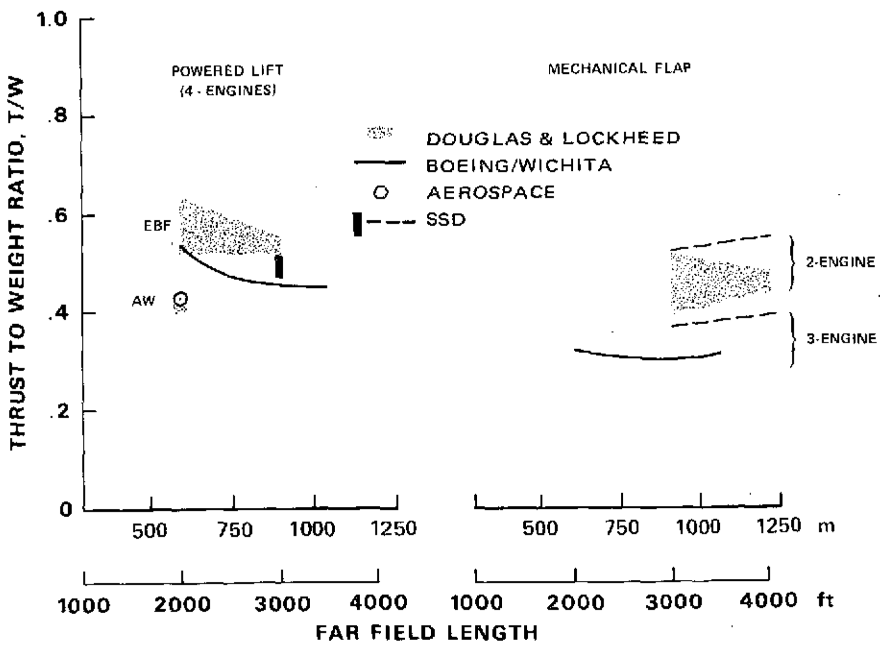


Figure 8.– Thrust requirements.

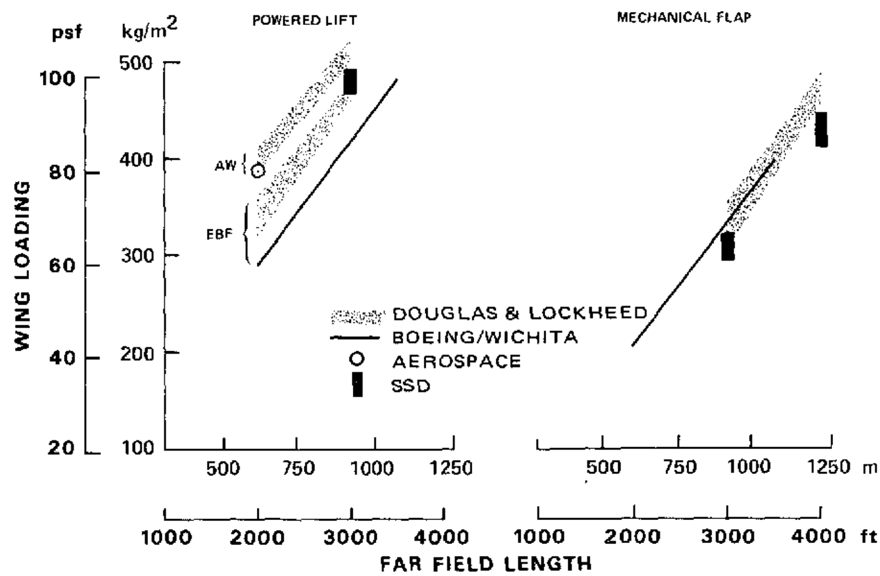


Figure 9.– Wing loading comparisons.

The augmentor wing configuration used by Aerospace weighs considerably less than the other powered-lift concepts for a 610 m (2000 ft) field length capability. Approximately 6770 kg (15,000 lb) of this difference can be attributed to the use of composites. However, the primary factor is that this configuration was based on a very early augmentor wing design, and as a result of more detailed design analysis and acoustic treatment, as indicated in reference 10, the vehicle weighs approximately 86,600 kg (192,000 lb), excluding composites, as shown in table 6. The primary effect of the lower weight used by Aerospace is on the economics as will be discussed later.

Figures 8 and 9 show the thrust loading and wing loading of the configurations as a function of field length. Figure 8 depicts the rated or uninstalled thrust-to-weight ratio of the various designs for varying wing loadings as shown in figure 9. The powered-lift configurations indicated are the AW and EBF concepts. The AW has lower thrust loadings and higher wing loadings for a given field length than does the EBF. Since the Boeing/Wichita vehicles emit higher noise levels and were designed for standard temperature field length, the engines are not subject to the associated losses resulting from extensive acoustic treatment and the higher atmospheric temperatures considered in the Douglas and Lockheed studies. This results in lower thrust loadings as shown in figure 8. Lockheed's designs are represented by the upper portion of the shaded band and the Douglas designs relate to the lower portion.

The broken line represents the SSD analysis of the effect of number of engines on the thrust requirements for a MF design. The purpose of this analysis was to facilitate comparison of the Boeing three-engine designs and the Lockheed and Douglas twin-engine designs. Again, the Boeing/Wichita designs have lower thrust requirements than the three-engine SSD designs because of higher noise levels and the assumed standard temperature design conditions. For the MF, the upper portion of the shaded band (Lockheed designs) has a negative slope because the cruise thrust requirement, which is the sizing criteria for the Lockheed designs, decreases as wing loading increases.

As mentioned previously and as shown in figure 9, the AW had the highest wing loading for a given field length. The wing loading trend lines for the EBF and MF are actually closer than this figure indicates if one account for the differences in ground rules. The Boeing/Wichita ground rules required a touchdown sink rate of 1 m/sec (3 ft/sec), while the Lockheed and Douglas designs were 3.3 m/sec (10 ft/sec). For an EBF configuration with adverse ground effects, the higher sink rate allows wing loadings 39-49 kg/m^2 (8-10 psf) higher for a given field length. This would place the Boeing results in the middle of the shaded band for the EBF.

For the MF, the upper portion of the shaded band represents Douglas designs having an approach speed margin of 1.2 above stall instead of the normal 1.3 which the other MF configurations have. If this defference is eliminated, the Douglas designs then fall along the lower portion of the band as do the Lockheed designs. The difference between the Boeing MF line and the lower portion of the band is due to the differnce betwen standard day and hot day conditions.

Figure 9 also indicates that vehicles employing propulsive lift have significantly higher wing loadings than the mechanical flap concepts.

Noise considerations– The noise characteristics of the various short-haul concepts were a major consideration in the Lockheed, Douglas, and Aerospace studies. The Lockheed and Douglas studies had a design goal of 95 EPNdB at 152 m (500 ft) sideline. Aerospace used the slant range noise characteristics of the aircraft described in reference 10 to analyze its community impact, whereas Boeing/Wichita's basic designs were not restricted to a specific noise criteria.

Figure 10 shows the area within the 95 EPNdB contour as a function of the noise level at 152 m (500 ft) sideline for the various concepts. The concepts represent powered lift with field length capability varying from 610 to 1066 m (2000 to 3500 ft) and MF concepts varying from 610 to 1220 m (2000 to 4000 ft) in field length capability. For comparative purposes, standard, refanned, and short-field refanned DC-9 class vehicles are also included. The modified DC-9 noise results are based on analyses performed by the SSD.

The shaded band represents Lockheed's short field designs using a variety of engine cycle fan pressure ratios, which resulted in different sideline noise values. This band also encompasses a variety of lift concepts and field length capabilities varying from 610 to 1220 m (2000 to 4000 ft). The bar at 95 EPNdB represents the noise characteristic of the Douglas designs which were all designed to this specific guideline. The solid bars at 111 EPNdB and 126 EPNdB represent the Boeing/Wichita MF and EBF, respectively, for field length capabilities varying from 610 to 1066 m (2000 to 3500 ft). The bar at 90 EPNdB represents the Aerospace 610 m (2000 ft) AW. The top part of the bar represents the area calculated by Aerospace; the bottom part represents the area as determined by the SSD using the slant range EPNL and flight profile data presented in the Aerospace report. Aerospace actually used a noise level of 95 EPNdB at a flyover distance of 152 m (500 ft). As indicated in reference 10 and by SSD's analysis, this corresponds to approximately 90 EPNdB at 152 m (500 ft) sideline when shielding and excess ground attenuation are taken into account.

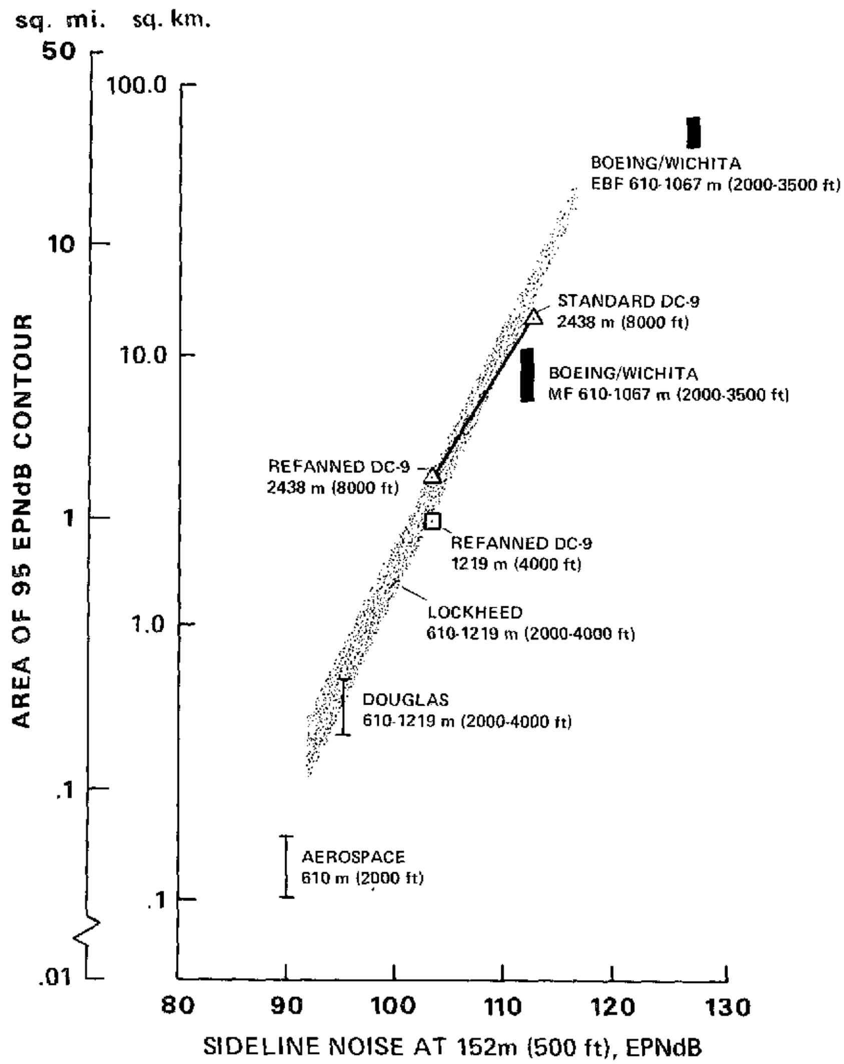


Figure 10.– Community impact of sideline noise design criteria.

The data point represented by the triangle at 112 EPNdB represents a standard DC-9 with a field length of about 2438 m (8000 ft) using a climb-out with throttle cutback and a normal 3° approach. The triangular data point at 103 EPNdB represents a DC-9 with a refanned engine and the same operational procedure as the standard DC-9 with improved high lift devices for a 1220-m (4000-ft) field length capability and operating on a steeper approach and steeper climb-out with cutback.

The contour area shown in figure 10 is associated with the 95 EPNdB contour, which would be contained essentially in proximity to most airports and thus would not necessarily be the noise level of most interest to the community. Figure 11 shows the contour area for various noise contours and design concepts designed to different 152-m (500-ft) sideline noise levels. For the standard and refanned DC-9, thrust cutback at an altitude of about 610 m *2000 ft) was used during the climb-out. This caused the areas of all the contours to be reduced in the standard DC-9 case, but

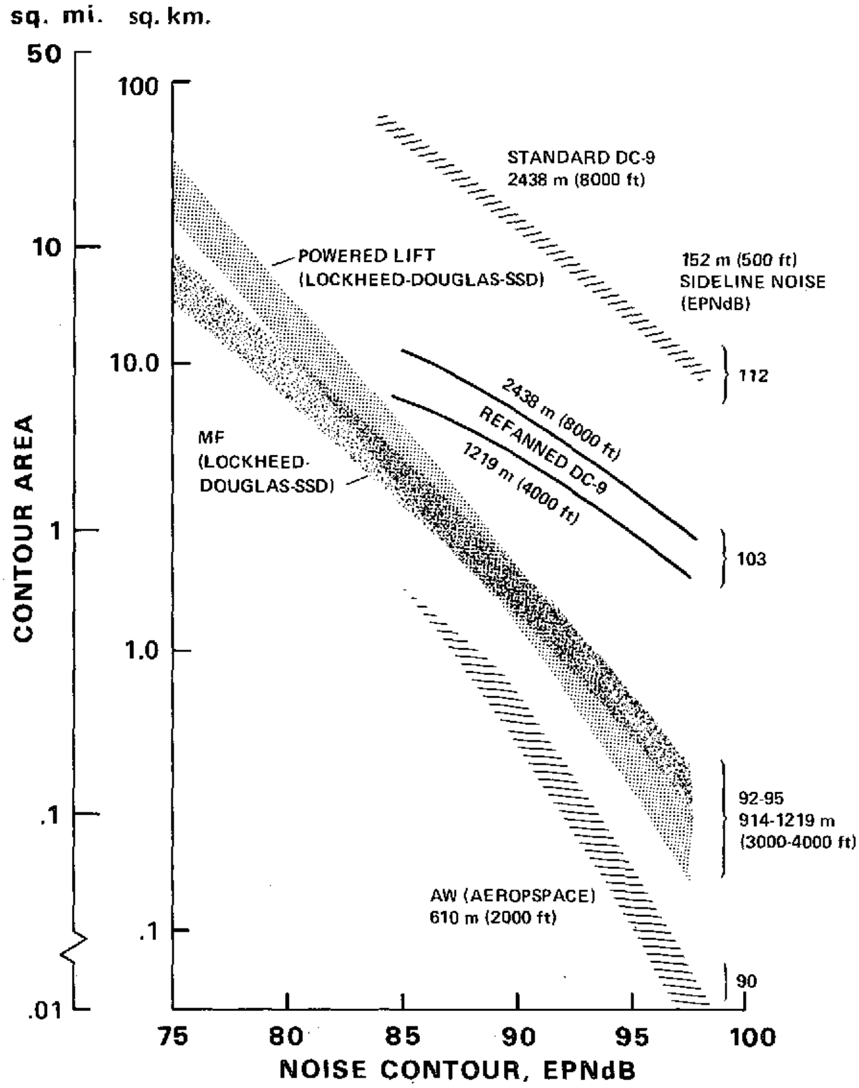


Figure 11.– Variation of contour area with noise contour.

only reduces the area of those contours equal to and greater than 90 EPNdB for the refanned configurations, because of the substantially reduced source noise associated with the latter. The shaded bands in the middle of the figure represent the powered-lift and mechanical flap designs of Lockheed and Douglas. Calculations of contour areas performed by the SSD using the slant range data as presented by Douglas in figure 12 yielded results that lie approximately in the center of the EBF and MF shaded variations. No throttle cutback was used during climb-out for these designs. Had throttle cutback been employed, somewhat lower contour areas would have resulted for the 75 and 80 EPNdB contours. Contour areas for contours greater than 80 EPNdB are little affected for these designs. It is interesting to note from figure 11 that the MF designs impact more area at the higher noise levels, whereas at the lower noise levels the powered-lift concepts impact more area. This is due to the differences in slope of the slant range noise data and the slight differences in climb angles between the concepts. The difference in slope is caused by the differences in engine cycles and by the low frequency flap interaction noise generated by powered lift.

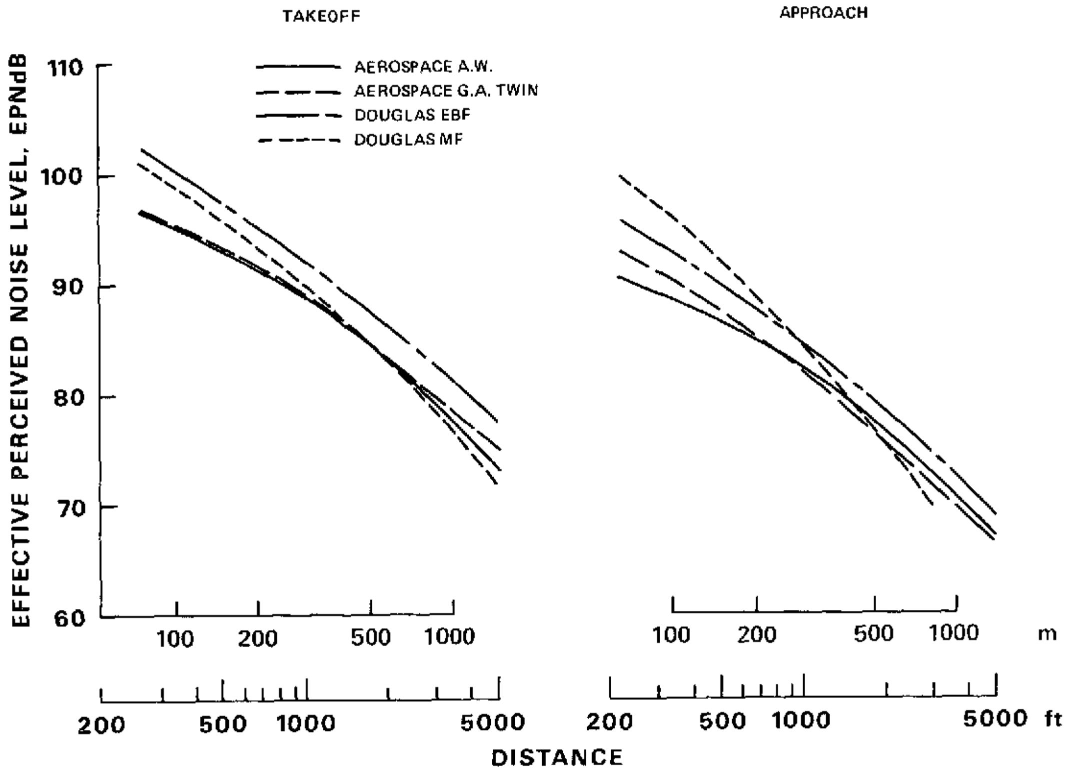


Figure 12.– Aircraft noise characteristics.

The band labeled AW Aerospace in figure 11 represents a powered-lift design based on the acoustic treatment analysis of reference 10. The upper part of the band represents contour data taken directly from the Aerospace report, while the lower part of the band represents the contours determined by SSD using slant range noise data contained in the Aerospace report. An aircraft with this type of noise characteristic generates noise levels very similar to light twin-engine general aviation aircraft and thus has very little impact when introduced into an airport. This can be seen by comparing the Aerospace slant range noise data for the AW and the general aviation twin-engine airplane in figure 12, which were taken directly from the Aerospace final report and therefore these data lead to the conclusion of the Aerospace study that STOL systems would have little, if any, community impact.

Another important conclusion can be derived from the trends shown in figure 11. Note that there is relatively little variation in contour area with field length capability (as indicated by the width of the various bands and excursions at specific sideline noise levels) compared to the rather steep variation in contour area with design sideline noise. The implication is that treatment of the noise at the source (i.e., acoustic treatment of the propulsion system) appears to be the most effective way to achieve low noise.

The cost of quieting, of course is another side to the noise problem. In an attempt to gain some insight into this aspect of the problem, the results of the Douglas and Lockheed studies are shown in figure 13 in the form of relative direct operating cost increases associated with designing for low sideline noise levels and designing for short field length capability. To obtain consistent cost variations, the DOC's generated by each contractor were normalized to the DOC of the corresponding contractor's advanced CTOL as indicated in the figure. As in the case of noise contour area described previously, the Douglas data are available for only one noise sideline level; however, the data are available for various field length capabilities. Significant increases in DOC are seen to occur for aircraft designed for decreasing levels of sideline noise. For example, for a field length capability of 914 m (3000 ft), an aircraft designed for 95 EPNdB (FAR 36-20) has an incremental increase in DOC of approximately 15 percent compared to one designed for 105 EPNdB (FAR 36-10). It can also be seen that designing for short field length capability further significantly increases these DOC cost increments.

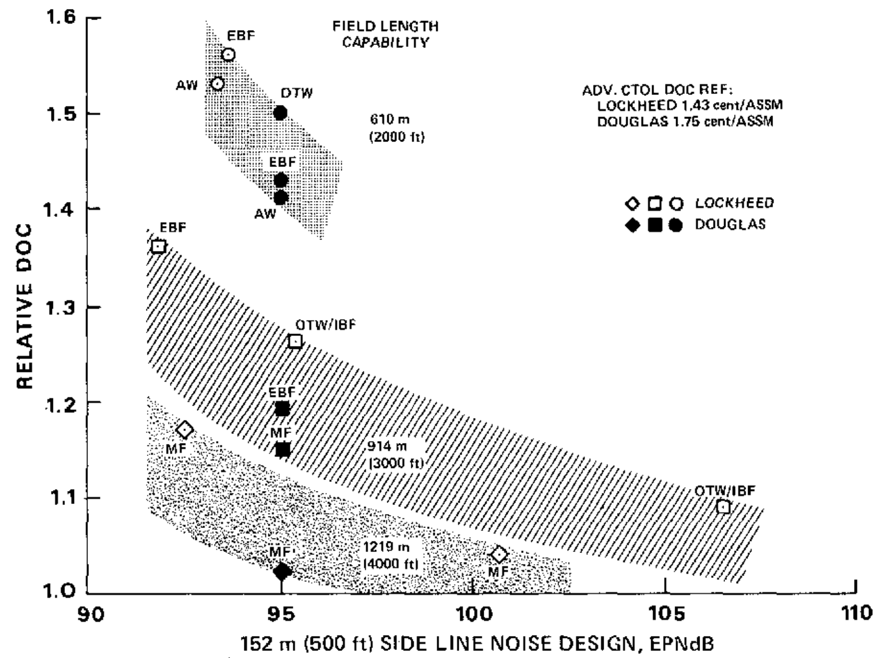


Figure 13.– Effect of quieting on DOC.

Advanced composite materials– Due to operational differences between long- and short-haul aircraft systems, there may be differences in the philosophy of application of composite materials. For example, the lower fuel weight to gross weight fraction of short-haul aircraft results in a higher payload weight fraction compared to long-haul aircraft weight fractions. Thus, short-haul aircraft tend to be less sensitive to structural weight change. On the other hand, maintenance costs for short haul are relatively high due to the larger number of flights per day. Thus, applications of composites to short-haul aircraft may be expected to be oriented more toward low cost and less toward low weight than for long-haul aircraft.

The procedure used by Douglas to arrive at life cycle structure costs in the STOL Composites Study (ref. 3) is shown in figure 14. Using the aluminum aircraft as a baseline, trade studies were made to determine cost effective applications of composites. For the selected designs, drawings were made in sufficient detail to allow itemized estimation of manufacturing cost. Other structure costs were then estimated and added to give total structure costs. All costs other than structure costs were estimated in the same way as for the baseline airplane in the STOL systems study (ref. 1).

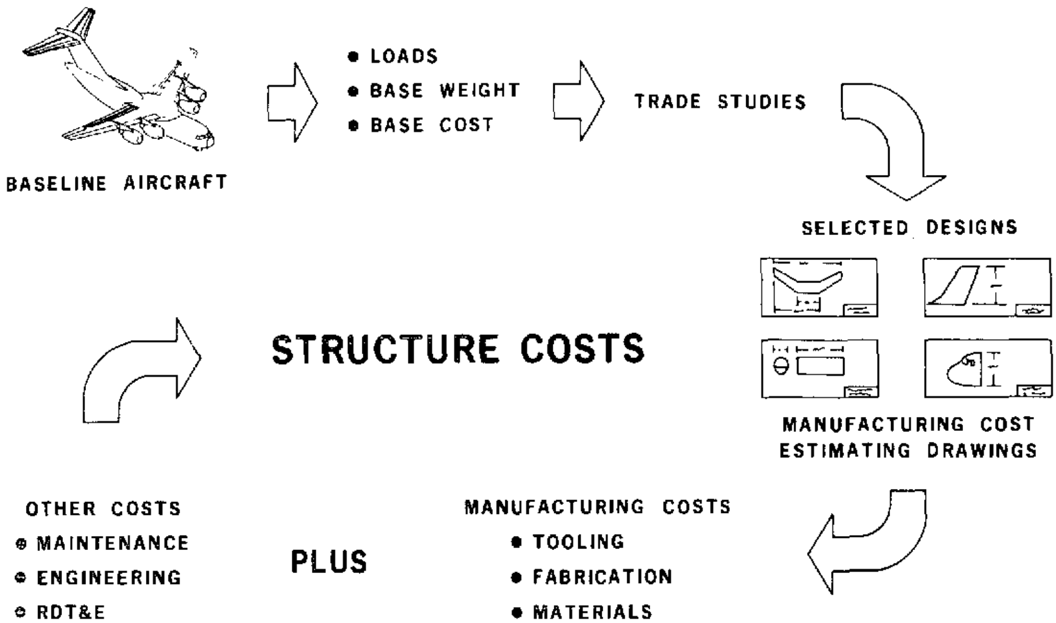


Figure 14.– Structures-costing methodology.

The selected structural concepts for the wing, fuselage, and empannage made extensive use of honeycomb sandwich with graphite/epoxy face sheets and aluminum core. As shown in figure 15, this resulted in a 26.7 percent decrease in airframe weight compared to conventional aluminum structure. The weight reduction was significantly higher in the wing and empannage than in the fuselage. Due to re-sizing, the weights of the propulsion system and other items also decreased, and the net effect was an 11.2 percent decrease in the gross takeoff weight. Figure 15 also shows the distribution of material in the airframe, which indicates that composite materials are about 40 percent of the total.

Table 7 shows the economic impact of composites application to STOL. Because of the uncertainty in raw material and maintenacne costs for composites, low, medium, and high estimates are given. Note that the low cost estimates result in composite airplanes that are economically superior to aluminum airplanes. The opposite result is obtained if the high estimates are adopted. This demonstrates the sensitivity to cost factors of the cost effectiveness of composite materials to STOL aircraft and indicates that further research into composite design for low cost is needed to define these costs.

TABLE 7.– COMPOSITE AIRPLANE ECONOMICS

(a) Unit price

All-composite	Low material cost	$\$11.19 \times 10^6$
	Nominal	11.50
	High	11.63
Reinforced metal fuselage	Nominal	11.30

Aluminum: $\$11.53 \times 10^6$

(b) Direct operating cost

		Maintenance cost estimate	
		Low, ¢/mi.[2]	High, ¢/mi.[2]
All-composite	Low material cost	1.92	1.98
	Nominal	1.95	2.03
	High	1.96	2.06
Reinforced metal fuselage	Nominal	1.93	1.96

Aluminum: 1.99 ¢/mi.[2]

(c) Return on investment

		Maintenance cost estimate	
		Low, percent	High, percent
All-composite	Low material cost	17.4	16.6
	Nominal	16.7	15.8
	High	———	15.5
Reinforced metal fuselage	Nominal	———	16.7

Aluminum: 16.2%

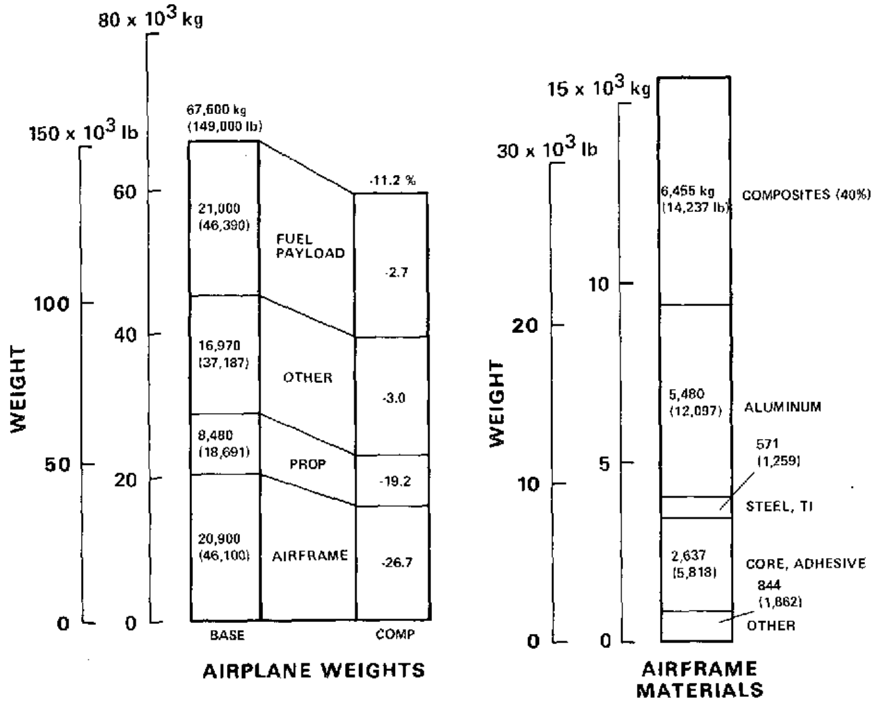


Figure 15.– Effect of composites on airplane weights.

Because of the low weight savings and high costs of the all-composite fuselage, an alternate concept was defined that employed a boron/epoxy reinforced metal fuselage but retained the all-composite wing and empennage. Table 7 shows this concept to be more cost-effective than the design with the all-composite fuselage.

Lockheed considered the impact of advanced composites as part of their systems study (ref. 2) although in much less depth than did Douglas in the STOL composites study. Lockheed's nominal aircraft design employed boron/epoxy uniaxial selective reinforcement of the center wing box section. In addition, use of graphite/epoxy all-composite structure was investigated parametrically. This investigation used complexity factors relating weight and cost of composite structure to that of aluminum which were developed in the Lockheed advanced transport technology study (ref. 11). The results of this parametric study indicated that heavy usage of graphite/epoxy was cost effective.

Although the Aerospace Corporation study (ref. 4) considered an augmentor wing aircraft consisting of 15 percent composite material, no comparisons were made with all-aluminum designs.

Economic Analysis

The future economic viability of short-haul air transportation may rest on its ability to recover operating costs and provide a return on invested capital. Previous studies have differed widely in their conclusions regarding the economic viability of STOL aircraft. These differing conclusions reflected differences in assumptions regarding market demand and operating economics, as well as various levels of technology in the aircraft designs studied. In addition, special advantages and disadvantages were attributed to the STOL system relative to CTOL operations, including fare premiums, more severe noise constraints, or other factors that in some way biased the results of each study.

Since the current studies were an attempt to resolve some of the economic questions raised by previous studies, econimic analysis was an integral part of these studies. Even in this case, however, differences in economic results were obtained, although two of the contractors, Lockheed and Douglas, were working in response to an identical work statement. However, it must be recognized that air transportation economics are highly leveraged. That is, the net profit represents a very small difference between large values of revenue and expense. Thus, variations in economic assumptions or in aircraft performance estimates can markedly alter the results obtained.

This section relates the economic methodology and results of the contract studies. Differences in approach are discussed and the economic sensitivities to aircraft performance and system operating parameters are evaluated. The results of the various study contractors are examined in light of the economic assumptions used, and are compared under a common set of assumptions in an attempt to reconcile the conclusions of these and previous studies.

Aircraft costs– The selling prices estimated by the various contractors for alternative point designs of a 150-passenger aircraft are compared as a function of field length in figure 16. These prices are the estimates as reported by each contractor, and have not been adjusted for differences in economic guidelines or other factors.

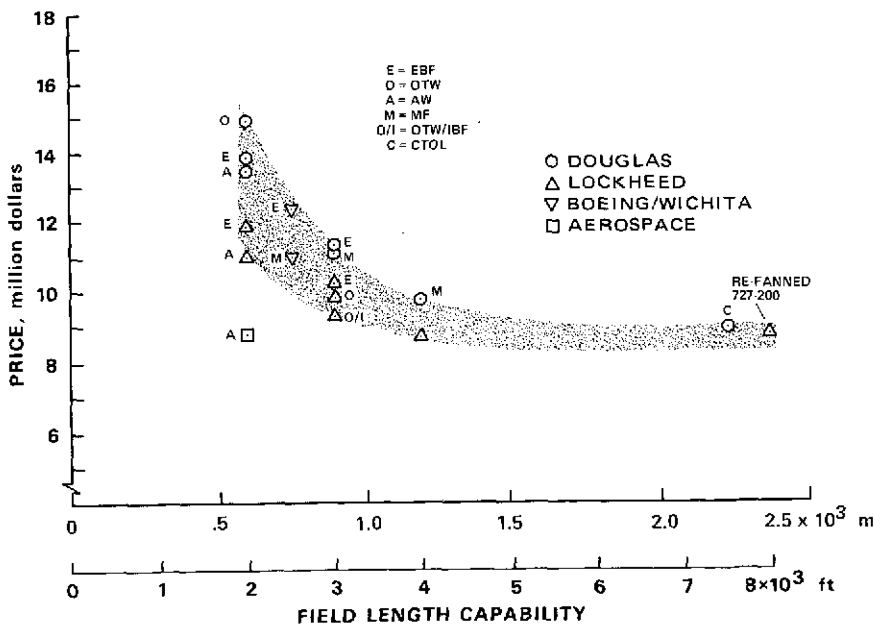


Figure 16.– Reported aircraft price estimates.

A direct comparison of different contractors' results can be made only for a limited number of point designs. Note, however, that the price differential between concepts for any contractor is less than the price differential between contractors for a given lift concept. These price differences between contractors reflect differences in estimated aircraft size and weight, and in pricing methodology.

The aircraft price estimates shown in figure 16 were computed with parametric pricing models based on historical cost data for transport aircraft development and production. The effects of production quantity, aircraft size, and manufacturer's profit are included in the selling price. Since the methods exhibit a strong relationship between airframe weight and price, differences between concepts for any one contractor are primarily due to empty weight differences.

	Aerospace	Boeing/ Wichita	Douglas	Lockheed
Production quantity	325	---	400	300
Manufacturer's profit	---	---	10%	5.5%
Economic base year	1970	1972	1972	1972

Note that, although Boeing did not specify the pricing assumptions used, differences exist in the other contractors' assumptions with regard to all three pricing factors.

Increases in production quantity affect unit price through cost reductions realized by "learning" in the manufacturing process and through the unit allocation of research and development costs. The difference between an assumption of 300 or 400 aircraft yields a final aircraft price differential of about 13 percent according to Douglas results.

Figure 17 illustrates the price estimates normalized to a production quantity of 300 aircraft, a 1972 economic base, and a 10 percent manufacturer's profit. The Boeing data were not included because the original pricing strategy was not specified. Note that the price differential between Douglas and Lockheed is increased by the normalization. This is due to the effect of production quantity in the original estimates.

The Douglas price estimates are for their "systems analysis" aircraft, for which operating economics were computed. The two crossed points at 914 m (3000 ft) field length represent the Douglas "final designs" for the EBF and MF concepts. Although the final design excursions changed the relative position of the two concepts at 914 m (3000 ft), the effect on the overall economic performance is small.

The insert in figure 17 illustrates the normalized aircraft price sensitivity to empty weight for the 610 m (2000 ft) field length augmentor wing aircraft. Note that the price differences between contractors appear to be due more to aircraft weight differences than to pricing factors.

The dashed line in figure 17 indicates that a 10 percent price reduction is obtainable with use of current-technology engines on the Lockheed vehicles. Such aircraft are, of course, not as quiet as those represented by the Lockheed, Douglas, and Aerospace data. This provides one measure of the economic penalty imposed by noise restrictions.

In the following section on *"operating economics"* the contractor results are analyzed in terms of *"operational concept", "direct operating cost", "indirect operating cost"*, and *"return on investment"*.

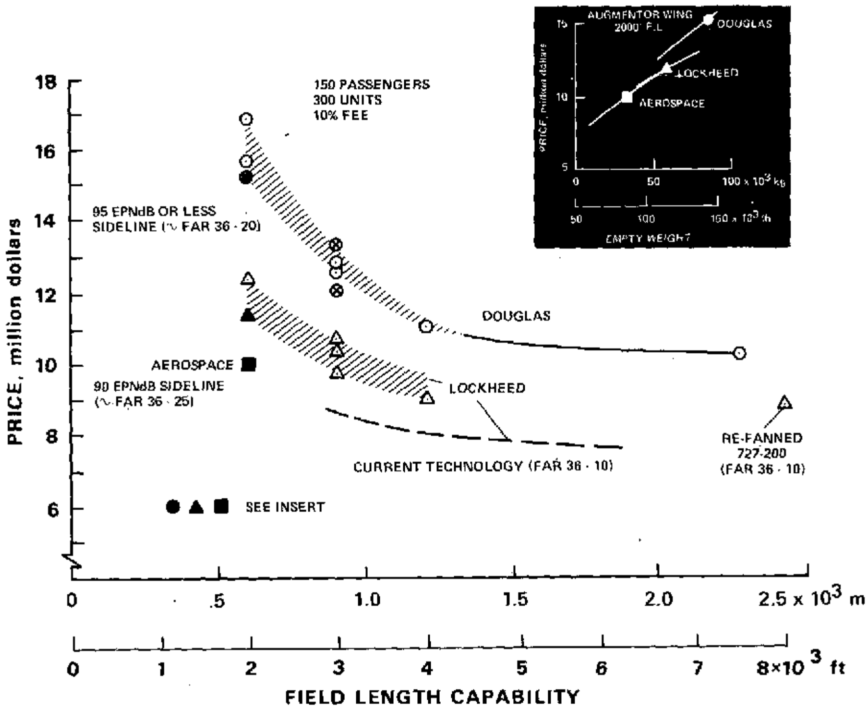


Figure 17.– Normalized aircraft price estimates.

Operating economics– Differences in *operational concept* account for part of the differences in economic results of the various contractors. Douglas examined the market in several high-density air travel regions and estimated the total passenger demand that could be captured by a dedicated short-haul system serving satellite airports. Since the assumed operational concept was a monopoly, it was deemed possible to schedule flight frequency in order to maintain an average of 60 percent passenger load factor, Lockheed examined the potential market in selected high-density short-haul segments within the present route structure of two carriers. Schedule frequencies and passenger demand assumptions led to average load factors of 55 percent for a mixed STOL/CTOL fleet. Aerospace assumed an operational concept similar to that of Douglas. The load factor assumed was 65 percent.

Load factor is very important to economic viability. The local service airlines, operating predominantly short haul service, have experienced an average passenger load factor of 44.7 percent over the 12-year period from 1960 to 1971. In this same period, these airlines suffered a total net loss of $120 million, despite a federal subsidy that averaged $55 million annually. With the higher load factors hypothesized by the contractors, this economic picture could be much different. It is estimated that up to 90 percent of additional revenue gained by a load factor increase passes through to operating profit, with only 10 percent being required to offset additional operating expenses.

All four contractors used *direct operating cost* (DOC) models based on the 1967 Air Transport Association (ATA) method. Since the ATA equations were developed for conventional takeoff and landing (CTOL) aircraft in long haul service, some changes were necessary to reflect the operating characteristics unique to a STOL short-haul system. In addition, the ATA model presents costs in

1967 dollars. Douglas, Boeing and Lockheed applied escalation factors which present the results in 1972 dollars. However, Aerospace used a Boeing DOC model which yielded results in 1970 dollars. Table 8 presents the three contractors' assumptions used in calculating DOC. The NASA column was used to normalize the contractors' DOC results, as discussed below, and is shown only for reference.

Since the Stanford analysis was based on the Douglas EBF designs, the aircraft price and DOC used by Stanford are identical to those of Douglas.

TABLE 8.– DIRECT OPERATING COST ASSUMPTIONS

	Study contractors			
Operating characteristics	Aerospace	Douglas	Lockheed	NASA
Annual utilization, hrs	3100	2500	2500	2500
Depreciation guidelines				
Aircraft life, yrs	14	12	12	12
Residual value, percent	2	0	15	0
Insurance rate, percent	2	2	1.2	1.2
Fuel cost, ¢/gal	12.1	11.5	12.7	12.7
Maintenance labor rate, $/hr	5.00	6.00	6.00	6.00
Maintenance manhour factor				
Percent adjustment for STOL - Airframe	+30	–25	–32.5	–25
- Engine	+30	–25	–25	–25
Engine spares factor, percent	30	25	25	25
Maintenance burden	2.0	1.8	1.3	1.8

Figure 18 compares DOC as a function of field length for the 150-passenger aircraft designs at a 924 km (575 mi.) stage length. The Aerospace DOC was extrapolated to 924 km (575 mi.) from the reported value at 805 km (500 mi). All DOCs shown are for aircraft that can meet a design noise level of 95 EPNdB at 152 m (500 ft) sideline, except for the two 727 points which are shown for reference. Although Boeing reported DOC, the estimates are not shown in figure 18 since the Boeing aircraft were not quieted to the same extent as the other contractor's aircraft. It should be noted, however, that the Boeing estimates lie within the DOC band of Lockheed and Douglas data. Figure 18 indicates that there is little economic penalty in reducing field length performance to 1219 m (4000 ft), but a DOC increase of about 10 percent is incurred at 914 m (3000 ft). A further reduction of field length performance requirement to 610 m (2000 ft) adds another 15 to 20 percent to DOC.

There is the same disparity between estimates of DOC as noted for aircraft price; the DOC differences between contractors are greater than the differences between concepts, particularly at 610 m (2000 ft) field length. This is primarily due to the large differences between contractor estimates of weight and performance, although some differences also exist in the DOC assumptions, as discussed below.

Table 9 compares the elements of direct operating cost estimated by Aerospace, Douglas and Lockheed for a 150-passenger augmentor wing 610 m (2000 ft). Also shown are the Douglas and Lockheed estimates for a 914 m (3000 ft) EBF design. The major difference between the cost to

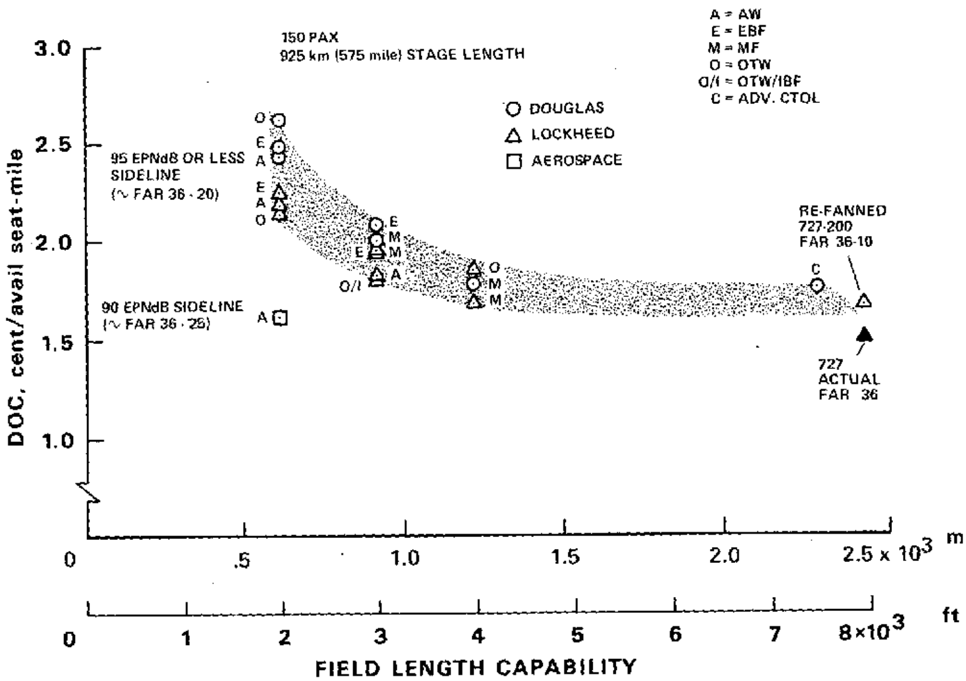


Figure 18.– Direct operating cost comparisons.

TABLE 9.– DIRECT OPERATING COST COMPARISONS ($ PER TRIP)
[150 Passenger aircraft, 924-km (575 mi.) stage length]

Operating cost guidelines	610 m (2000 ft) Augmentor wing			914 m (3000 ft) EBF	
	Aerospace	Douglas	Lockheed	Douglas	Lockheed
Flight crew	198	277	247	298	247
Fuel	338	458	495	247	293
Insurance	77	147	69	130	69
Depreciation	311	692	500	622	483
Maintenance	230	321	288	311	288
Maintenance burden	146	221	138	199	121
Total	1300	2116	1737	1798	1501
Normalized DOC	1620	2253	1860	1934	1559

operate the 610 m (2000 ft) augmentor wing and the 914 m (3000 ft) EBF is in fuel consumption, which is 67 percent higher by Lockheed's estimate and 85 percent higher for the Douglas augmentor wing design. About one-third of this increase is due to the field length performance and about two-thirds is due to the higher fan pressure ratio of the augmentor wing concept.

Aircraft depreciation and insurance combined represent both the largest element of DOC and the area of greatest disparity between contractors. This reflects the large differences in aircraft price estimates noted previously, and, to a lesser extent, methodological differences indicated in table 8. Other differences in the DOC values of table 9 are due to the differences in aircraft price, weight, and estimating methodology.

Table 9 also compares the DOC normalized to a consistent set of guidelines. The "NASA" guidelines shown in table 8 were used for this comparison. The normalized aircraft prices of figure 17 were used, and each contractors' estimate of fuel consumption and design weight was applied.

The *indirect operating cost* (IOC) estimates of Aerospace, Douglas, and Lockheed are shown as a function of stage length in figure 19. Boeing did not compute IOC. Since IOC is related more to operational philosophy than aircraft performance, IOC differences due to aircraft design concept are very small and are not presented here.

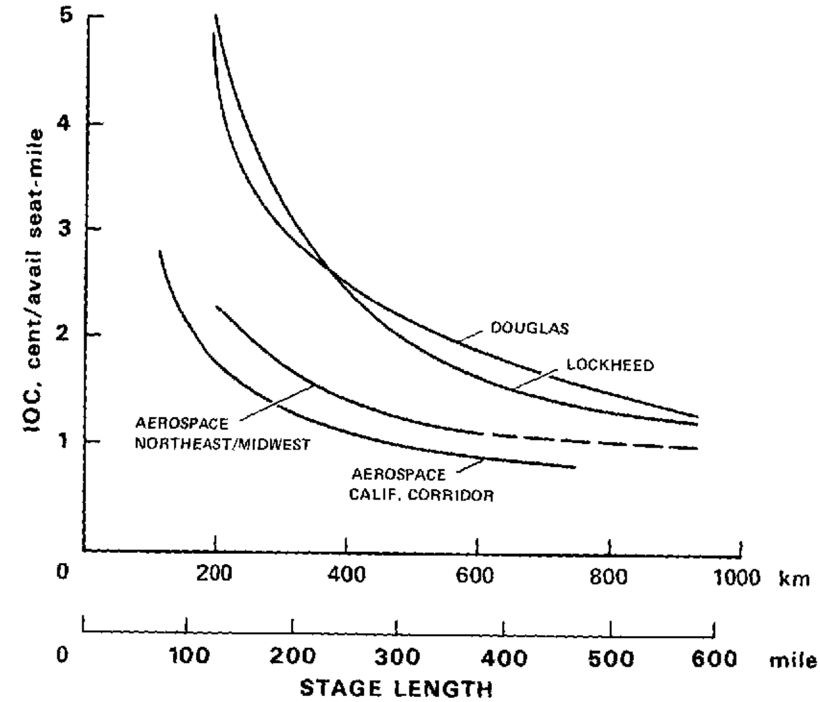


Figure 19.– Indirect operating cost comparisons.

The Douglas and Lockheed IOC estimates are very similar and are computed with nearly identical models. These models are based on 1971 IOC experience of the domestic trunk airlines, modified for unique operational features of the short haul system. The Aerospace estimates are based on a similarly derived IOC model, but reflect the IOC experience of Pacific Southwest Airlines (PSA) for the California Corridor calculations, and a mixture of PSA and trunk IOC factors for the Northeast Corridor and Midwest Triangle calculations. The IOC values used in the Stanford study are also based on actual PSA experience and, hence, are identical to the Aerospace curve for the California corridor in figure 19.

Douglas and Lockheed modifications to domestic trunk IOC values are as follows: (1) system expenses were reduced 25 percent to reflect the savings in ground property and equipment costs from using a single type of aircraft; (2) aircraft control costs were reduced 20 percent since a regional system would use centralized facilities for flight planning, crew scheduling and meteorology; (3) food and beverage services were reduced by 80 percent since the flights will be of relatively short duration; (4) passenger ground service costs were reduced 35 percent to reflect the more austere STOL service. All of these reductions are reflected in the IOC values of figure 19.

Lockheed postulated further IOC reductions, approaching the Aerospace values. Such reductions seem unlikely in a mixed STOL/CTOL operation such as that examined by Lockheed for the Eastern and Allegheny route systems. These reductions are more feasible in a dedicated short-haul operation such as that assumed by Douglas and Aerospace, particularly if the service is provided by an independent airline whose "corporate image" would not be jeopardized by such austere service. Certainly such IOC reductions would only be possible with high ratios of passengers per employee, as is now achieved by PSA. High productivity is best achieved with very high traffic density, such as that in the California Corridor.

Return on investment (ROI) is the ultimate measure of economic viability of a private enterprise. However, the computation of ROI is highly sensitive to differences in aircraft performance and price, operating economics, and differences in assumptions for load factor and revenue yield per passenger. Aerospace and Stanford used a 65 percent load factor and computed the fare level required to provide a fixed ROI in the respective regions considered. Aerospace considered a range of ROI's but final results were based on fare requirements for an 8 percent ROI, while Stanford investigated 12, 8, and 0 percent ROI. Douglas and Lockheed, on the other hand, assumed fixed fare levels and computed the resultant ROI. Lockheed used a 55 percent load factor and the current CAB-approved fare level, minus 13 percent revenue dilution for promotional fares. The assumed load factor and the revenue dilution factor are both consistent with Lockheed's assumption of a mixed CTOL/STOL operation. Douglas used a 60 percent load factor and no fare dilution, and also included a $0.37 revenue per passenger for alcoholic beverage sales. The higher load factor and ticket revenue assumptions are consistent with the Douglas operational concept of a dedicated short-haul system, and the beverage revenue is representative of current airline experience on short-haul flights. In addition, the daily utilization assumed for each aircraft is 8.7 hr for Aerospace, 8.2 for Stanford, 7.6 for Douglas, and 7.0 for Lockheed.

All these factors affect the annual revenue, and hence the ROI. These and other differences in the estimating methodology preclude any attempt to compare the reported ROIs. Instead, a new value of ROI was computed for several design point vehicles in order to compare the results of the various contractors. This ROI was based on a consistent set of assumptions, including a 55 percent load factor, no fare dilution, and no beverage revenue. The normalized aircraft price was used, although each contractor's own value of operating cost was used in the ROI calculation.

Figure 20 compares the results for the 610 m (2000 ft) augmentor wing, the 914 m (3000 ft) EBF, and the 1220 m (4000 ft) mechanical flap. The Douglas advanced CTOL and a refanned 727-200 are shown for comparison. Since the refanned 727-200 would still be noisier than the study vehicles, the effect of a $2 per passenger noise tax is shown.

As expected, normalizing the ROI reverses the relative magnitude from the reported values. Since the Douglas aircraft have higher price and operating cost, the ROI should be the lowest, as is

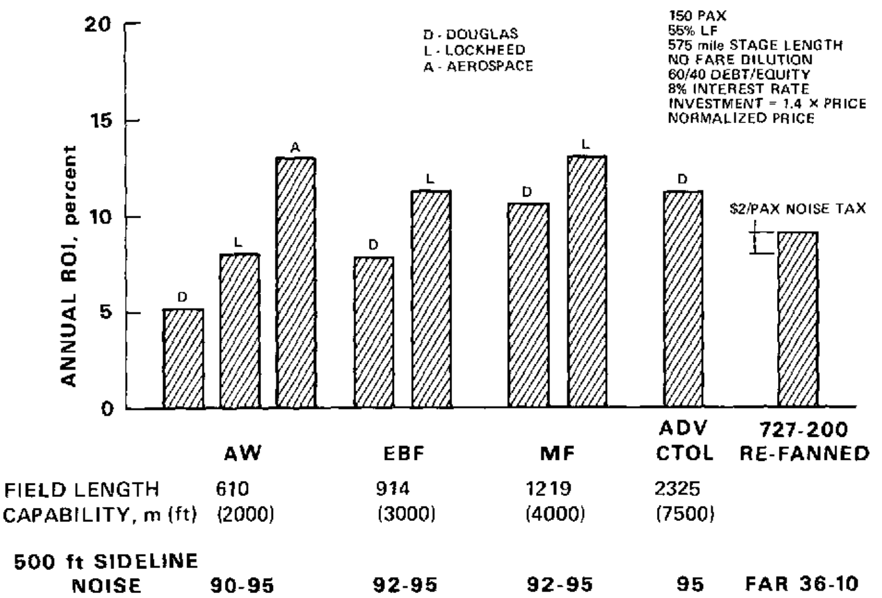


Figure 20.– Computed annual return on investment.

the case here. It should be noted here that consideration of Douglas' final design EBF aircraft would result in a one count increase in ROI. The 610 m (2000 ft) augmentor wing ROI ranges from 5 percent for the Douglas design, to 13 percent for the Aerospace design. ROI is improved with less severe field length performance requirements, although for field length capabilities above 1220 m (4000 ft) the ROI gain is small.

Technology Needs

The STOL systems studies conducted by Douglas and Lockheed were the only studies to address specifically the identification for NASA consideration of critical technology and technology-related problems to be resolved for successful introduction of representative STOL short-haul systems. Therefore, summarized below are the more pertinent technology areas that these studies have identified as requiring additional research and development effort.

QCSEE engine development– Technology advancement is required to establish the capability to produce quiet, clean, reliable variable pitch fan engines of the thrust level needed for STOL aircraft. The advantages of either direct-drive moderate tip speed fans or geared-drive low tip speed fans requires further assessment.

Acoustics– Flyover noise tests using various aircraft should be conducted to evaluate the magnitude and directivity patterns of airframe-generated noise and noise generated by blowing on, over and through the wing and flap surfaces as a function of pertinent aircraft parameters and to correlate the results with analytical models of the noise generating mechanisms.

Research is required to establish proper noise-measurement locations to ensure minimum negative community reaction and to permit more accurate evaluation of alternative aircraft designs.

Further analytical studies and experimental verification should be conducted of methods of reducing jet noise such as exploitation of acoustic feedback phenomena, retractable ejectors, and/or high-aspect ratio nozzles in over-the-wing applications.

Wake-vortex– The trailing vortex that will be generated by STOL aircraft may produce a powerful turbulent wake. Investigations are required of propulsive-lift aircraft to determine safe separation distances for all modes of operation.

Advanced lift concepts– Configurations using a combination of high lift concepts such as upper surface blowing in combination with internally blown trailing edge flaps, canard configurations, etc., should be investigated along with design application analyses so that experimental results can be correlated with practical operational applications.

Structures and materials– Validation of advanced composite structures requires substantial attention to promote acceptability, both to maufacturers and to airlines. This validation will require implementation of a wide range of programs that develop a large amount of production and operating experience. Expected payoffs for this technology application include reduced weights, improved manufacturability, and increased reliability through fatigue behavior.

Active controls technology– Further investigations are needed to assess the benefits of active controls technology concepts and their effect on weight and cost changes, maintenance requirements, and operational handling. Control configured vehicles utilizing a combination of controls such as wing flaps and canards and improved systems for gust alleviation and ride comfort should be included.

Conclusions

When results of all these studies are interpreted within the context of common guidelines and assumptions as used in the present evaluation, the authors derive the following general and specific conclusions:

General– STOL appears to be an economically viable means of reducing noise and air congestion at the major hub airports.

The implementation of STOL aircraft at secondary airports may pose serious social acceptance problems. For this reason and in view of the associated high economic risks, it appears to be desirable that initial implementation be at the major congested hubs utilizing separate STOL runways and terminals, with evolution to secondary airport utilization after congestion at the major hubs has been relieved. There are numerous existing airports that are favorably located for implementation of a STOL transportation system.

Specific– Aircraft sized for 150 passengers provide near-optimum capacities and schedule frequencies for high-density markets.

Anticipated noise levels of 20 EPNdB less than FAR 36 and relief of potential future airside congestion can be obtained with aircraft capable of takeoff and landing on runways up to 914 m (3000 ft). Aircraft with field length capability of 1219 m (4000 ft) may also be adequate. The latter have an associated reduction in direct operating cost (DOC) of approximately 10 percent and 25 percent compared to aircraft with field length capabilities of 914 m (3000 ft) and 610 m (2000 ft), respectively. The associated increases in return on investment (ROI) are approximately 20 percent and 60 percent.

There does not appear to be a requirement for aircraft with 610 m (2000 ft) to relieve airside congestion based on the fact that adequate runways 914 m (3000 ft) in length or greater already exist at secondary airports and could be added to most existing major hub airports.

Severe economic penalties are associated with a 95 EPNdB (20 EPNdB less than FAR 36) noise criterion at 152 m (500 ft) sideline. The incremental increase in DOC over advanced CTOL aircraft with 10 EPNdB less than FAR 36 are approximately 10, 15, and 45 percent for field length capabilities of 1219, 914, and 610 m (4000, 3000, and 2000 ft), respectively.

The introduction of quiet STOL in high-density markets in the mid-1980s requires immediate initiation of development of a quiet, economical engine with a thrust level between 9,070 and 11,314 kg (20,000 and 25,000 lb) and a fan pressure ratio in the range of 1.3 to 1.5.

The most significant technology areas requiring continued research are found to be:

Quiet clean experimental engine development (QCSEE)
Noise prediction and reduction research
Wake vortex and separation research
Advanced lift concepts development
Composite structure research
Active control technology R&D

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif. 94035, January 22, 1974

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